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CONTROL

SYSTEMS · INSTRUMENTATION · DATA PROCESSING · ENGINEERING · APPLICATIONS

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LOOKING FOR A JOB? Control *carries the best jobs in instrument and control engineering.* **SEE PAGE 184 AND ONWARDS**

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LOOKING AHEAD

Unless otherwise indicated, all events take place in London. B.C.A.C., British Conference on Automation and Computation. B.C.S., British Computer Society. Brit.I.R.E., British Institution of Radio Engineers. I.C.E., Institution of Civil Engineers. I.Chem.E., Institution of Chemical Engineers. I.E.E., Institution of Electrical Engineers. I.Mech.E., Institution of Mechanical Engineers. I.Prod.E., Institution of Production Engineers. I.S.A., Instrument Society of America. R.Ae.S., Royal Aeronautical Society. S.B.A.C., Society of British Aircraft Constructors. S.I.T., Society of Instrument Technology.

WEDNESDAY 12 APRIL
A symposium on *Materials of construction* at Birmingham University. Details: T. R. Bott, Chemical Engineering Dept, The University, Birmingham, 15. (*I.Chem.E.*)

THURSDAY 13 APRIL
The Graham Clark lecture: *Resources, human and material, of the Commonwealth*, by H.R.H. The Duke of Edinburgh. (*I.C.E.*)

MONDAY 17—WEDNESDAY 19 APRIL
7th National U.S.A. Symposium on *Instrumental methods of analysis*. Shamrock-Hilton Hotel, Houston, Texas, U.S.A. Details: Meetings Manager, I.S.A., 313 Sixth Av., Pittsburgh, 22, Pa, U.S.A.

TUESDAY 18—WEDNESDAY 19 APRIL
Science and industry—the problem of communication. Brangwyn Hall, Swansea. Registration: D.S.I.R. Liaison Officer for Wales, Block II, Government Bldgs, Gabalfa, Cardiff.

WEDNESDAY 19 APRIL
The design, application and selection of automatic control valves by P. Stone. 7 p.m. The Conference Room, Roadway House, Oxford St, Newcastle upon Tyne, 1. (*S.I.T*)
Electronic telephone exchanges by T. H. Flowers. 7 p.m. (*S.I.T.*)

WEDNESDAY 19—FRIDAY 21 APRIL
The 14th Annual Conference of the Institution of Plant Engineers. Details: The Institution of Plant Engineers, 2 Grosvenor Gdns, S.W.1.

THURSDAY 20 APRIL
One-day symposium on *Air traffic control*. R.Ae.S., 4 Hamilton Place, W.1.

THURSDAY 20 APRIL—THURSDAY 4 MAY
Engineering, Marine, Welding and Nuclear Energy Exhibition, Olympia.

TUESDAY 25 APRIL
Instrumentation in the iron and steel industry by A. H. Pople. 7 p.m. (*S.I.T.*)

WEDNESDAY 26 APRIL
Symposium on *Electronic counting techniques*. 6.30 p.m. (*Brit. I.R.E.*)

FRIDAY 28 APRIL
Techniques for digital data links. A lecture demonstration by T. D. Towers at the London School of Hygiene and Tropical Medicine. Details: W. Birtwistle, 78 Shaw Rd, Rochdale, Lancs.

SUNDAY 30 APRIL—THURSDAY 4 MAY
7th National aero-space instrumentation symposium. Adolphus Hotel, Dallas, Texas., Details: W. J. Gabriel, Convair Divn, General Dynamics Corp., Ft Worth, Texas, U.S.A.

WEDNESDAY 3 MAY
Symposium on *Computer control of air traffic*. 5.30 p.m. (*Brit. I.R.E.*)

WEDNESDAY 3—THURSDAY 4 MAY
Railway modernization. A conference organized jointly by I.C.E., I.Mech.E., and I.E.E. Details: (*I.C.E.*)

WEDNESDAY 3—SATURDAY 13 MAY
British Columbia International Trade Fair, Exhibition Park, Vancouver, Canada.

MONDAY 8—WEDNESDAY 10 MAY
4th National I.S.A. Power Instrumentation Symposium. La Salle Hotel, Chicago, Ill., U.S.A. Details: Meetings Manager, I.S.A., 313 Sixth Av., Pittsburgh, 22, Pa, U.S.A.

TUESDAY 9—WEDNESDAY 10 MAY
Standards Engineers Conference. Details: B.S.I., 2 Park St, W.1.

TUESDAY 9—WEDNESDAY 17 MAY
International Exhibition of Measurement, Control, Regulation and Automation (Mesucora) and 58th Exhibition of French Physical Society. C.N.I.T., Paris. Secrétariat Général, 40, rue du Colisée, Paris, 8e, France.

WEDNESDAY 10—FRIDAY 12 MAY
Pulp and Paper Instrumentation Symposium. Northland Hotel, Green Bay, Wisc., U.S.A. Sponsors: I.S.A. and T.A.P.P.I. Details: Meetings Manager, I.S.A., 313 Sixth Av., Pittsburgh, 22, Pa, U.S.A.

An international conference on *Materials handling*. Southport. Details: Institute of Materials Handling, 69 Cannon St, London, E.C.4.

FRIDAY 19 MAY—SUNDAY 4 JUNE
British Trade Fair, Moscow. Details: Industrial and Trade Fairs Ltd, Russell St, London, W.C.2.

MONDAY 22—WEDNESDAY 24 MAY
10th National Telemetering Conference, Hotel Morrison, Chicago, Ill., U.S.A., Sponsors: I.S.A., A.I.E.E., A.R.S., I.A.S., I.R.E. Details: Meetings Manager, I.S.A., 313 Sixth Av., Pittsburgh, 22, Pa, U.S.A.

WEDNESDAY 24 MAY—SUNDAY 4 JUNE
The 24th Salon International de L'Aéronautique, Le Bourget, Paris, France.

TUESDAY 30 MAY—FRIDAY 2 JUNE
Radio and Electronic Component Show, Olympia. Details: Industrial Exhibitions Ltd, 9 Argyll St, W.1.

TUESDAY 6—THURSDAY 8 JUNE
I.S.A. Summer Instrument-Automation Conference and Exhibition, Royal York Hotel and Queen Elizabeth Hall, Toronto, Ont., Canada. Details: Wm H. Kushnick, I.S.A., 313 Sixth Av., Pittsburgh, 22, Pa, U.S.A.

FRIDAY 9—SATURDAY 17 JUNE
13th Chemical Engineering Exhibition and Congress, Frankfurt am Main. Details: Dechema, Decheme-Haus, Rheingau-Allee 25, Frankfurt am Main, Germany.

MONDAY 12 JUNE
Air Pollution Instrumentation Symposium (with the June 12–16 annual meeting of the Air Pollution Control Association), Hotel Commodore, New York City, N.Y., U.S.A. Sponsors: I.S.A. and A.P.C.A. Details: Meetings Manager, I.S.A., 313 Sixth Av., Pittsburgh, 22, Pa, U.S.A.

MONDAY 12—THURSDAY 15 JUNE
British Electrical Power Convention: *Electricity in the prosperity and welfare of the nation*. Details: Electrical Development Association, 2 Savoy Hill, W.C.2.

MONDAY 12—SATURDAY 17 JUNE
Conference on *Components and materials used in electronic engineering*. Central Hall, Westminster, S.W.1. (*I.E.E.*)

TUESDAY 13—FRIDAY 16 JUNE
3rd Biennial International Gas Chromatography Symposium, Kellogg Center, Michigan State University, East Lansing, Mich., U.S.A. Details: Meetings Manager, I.S.A., 313 Sixth Av., Pittsburgh, 22, Pa, U.S.A.

THURSDAY 15—FRIDAY 16 JUNE
Two open days at Bisra's Sheffield Laboratories. Details: D. U. Hunt, B.I.S.R.A., 11 Park Lane, London, W.1.

MONDAY 19—FRIDAY 23 JUNE
6th International Instrument Show, 4 Tilney St, Park Lane, W.1. Sponsors: B. & K. Laboratories.

MONDAY 26 JUNE—SATURDAY 1 JULY
International Measurements Conference, (Imeko), Budapest. Details: Prof. J. F. Coales, Cambridge University, Trumpington St, Cambridge, or Imeko Secretariat, Budapest 5, P.O.B. 3, Hungary.

TUESDAY 27—FRIDAY 30 JUNE
A conference on *The social and economic effects of automation*, sponsored by members of the B.C.A.C. Applications for tickets to The British Institute of Management, 80 Fetter Lane, E.C.4.

WEDNESDAY 28—FRIDAY 30 JUNE
2nd Joint Automatic Control Conference. University of Colorado, Boulder, Colo., U.S.A. Sponsors: I.S.A., A.I.Ch.E., A.I.E.E., A.S.M.E., I.R.E. Details: Meetings Manager, I.S.A., 313 Sixth Av., Pittsburgh, 22, Pa, U.S.A.

LOOKING FURTHER AHEAD

WEDNESDAY 5—SATURDAY 9 JULY
Radio techniques and space research. A convention at Oxford University. (*Brit. I.R.E.*)

SUNDAY 16—FRIDAY 21 JULY
4th International Conference on *Medical electronics* at the Waldorf-Astoria, New York. Sponsors: I.R.E., A.I.E.E., I.S.A. Details: Institute of Radio Engineers, 1 East 79th St, New York City, N.Y., U.S.A.

WED. 30 AUGUST—WED. 6 SEPTEMBER
Annual Meeting, British Association for the Advancement of Science, Norwich. Details: Secretary, B.A.A.S., 19 Adam St, Strand, London, W.C.2.

MONDAY 4—SATURDAY 9 SEPTEMBER
3rd International Session of the International Association for Analogue Computation. Belgrade, Yugoslavia. Details: Yugoslav Committee for Etan, Terazije, 23/VII, Belgrade, Yugoslavia.

MONDAY 4—SUNDAY 10 SEPTEMBER
S.B.A.C. Flying display and exhibition, Farnborough. Details: S.B.A.C., 29 King St, St James's, London, S.W.1.

TUESDAY 5—FRIDAY 8 SEPTEMBER
An international conference on *Machine translation of language and applied language analysis*. National Physical Laboratory, Teddington, Middlesex. Papers to Dr A. M. Uttley, Autonomics Division, N.P.L.

WEDNESDAY 6—FRIDAY 8 SEPTEMBER
International Symposium on the *Transmission and processing of information*. Massachusetts Institute of Technology. Submission of papers is invited. Details: R. M. Fano, R.L.E., M.I.T., Cambridge, 39, Mass., U.S.A.

WEDNESDAY 4—THURSDAY 12 OCTOBER
Second Electronic Computer Exhibition and Symposium, London. Details: Mrs S. S. Elliott, 64 Cannon St, E.C.4.

APRIL 1961 VOL. 4 No. 34 CONTROL

The new Luddism

IN THE EARLY nineteenth century, during the first whirl of industrial revolution, working men feared for their jobs because the new labourers —machines—knew better how to ingratiate themselves with their employers. They were more effective and more efficient, less easily tired and less tiresome, and their prowess in many respects was obviously beyond reach of human competition. Poor, half-witted Ned Ludd left his mark on history in 1799 by breaking stocking frames. Later, in the years 1811 to 1816, bands of 'Luddites' roamed around the country smashing labour-saving machinery, burning factories, and trying vainly in other ways to halt their supposed adversary. Much as some may sneer at the short-sighted attitude of the Luddites, few can entirely suppress sympathy for their feelings.

In recent years there has been some slight resurgence of Luddism, and this has come about for much the same reasons as in the nineteenth century. Automatically controlled machines are now the bogy, at least in those more efficient firms where they are taking over. On the face of it the neo-Luddite argument is clear. Automatized plant produces more goods with less labour. Hence, if there were full automation, the labour force would be reduced to negligible size. Consequently it is against the workers' interests to admit the automatic equipment.

We have visited a great many firms in this country, and in our experience the neo-Luddite argument is disproved by events. In no case that we know has the introduction of automatic control led to the dismissal of labour. Users of automatic plant claim that their production is more efficient and their product better, yet in every instance they emphasize that the men whose labour they have saved do not become redundant but are employed elsewhere.

This apparently paradoxical ability to produce more with less labour and still not dismiss workpeople, it may be observed, arises from a happy coincidence: the better and more efficient organizations are the very ones that introduce automatic control, and they are also (therefore) the organizations that grow and prosper; their expansion absorbs the displaced labour. This cannot continue indefinitely, says the pessimist. The optimist, on the other hand, sees that there is a tremendous amount of industrial renovation required, particularly in older-established manufacturing countries like Britain, and adds that as this will all take time the demands of an 'affluent society' can be made to rise in such a way as to ease the transition from manual to robot labour.

The neo-Luddites deny that this is possible, and they have now found their evidence in that most automatized of countries, the United States. The American economy is suffering a serious recession. Unemployment was 5,705,000 in February, so about 7% of the total labour force was out of work. Why should the world's richest nation find herself in this position? The neo-Luddites blame it on automation, and disregard balance-of-payment problems and other politico-economic factors. There may be some truth in this, especially in the short term, but they have a far more serious charge to make, and one that is much harder to answer. Although automation may not be responsible for workers being *laid off*, it can be blamed for *shortage of vacancies*. In the words of an American politician, the trouble 'is not the worker who is fired but the worker who is not hired'. The American magazine *Time* has given figures that tend to confirm this. For example, chemical production has gone up 27% since 1956 although the industry employs 3% fewer people; steel-making capacity is 20% bigger than in 1955 although 17,000 fewer workers are engaged; and Bell telephones handle 50% more calls than they did ten years ago, with a mere 10% increase in labour.

In spite of these figures we find it difficult to believe that automatically controlled machinery is ultimately to blame for the general increase in American unemployment. The causes lie much deeper: but they exist, and they must be recognized and countered. Western industrial progress depends vitally on automation, and there must be no excuse for neo-Luddite wreckers to oppose it. Here is a really serious fundamental problem for the various governments. Let us hope they are up to it.

VIEWPOINT

H. G. Conway, Deputy Managing Director and Chief Engineer of Short Brothers and Harland, discusses the lay executive's problems in . . .

MANAGING THE CONTROL ENGINEER

The developments which have taken place in recent years in control engineering have introduced many new problems which management must face, not the least of which are personal to the managers themselves. While accountants are found in senior positions in some firms, in technical organizations a manager will usually have been drawn from the engineering or production ranks, and have had substantial experience of the practical problems of designing, developing and manufacturing the company's products. In many fields, particularly heavy engineering, ship-building, and the like, managers are often regarded with a respect based on the knowledge that, in their day, they too worked on a drawing board or a machine doing the same job that is now done by those under their control.

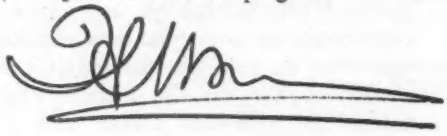
In many branches of control engineering today the position is quite different. Much of the truly creative work in the electronic and light precision mechanical fields which make up control engineering is done by young engineers, many of them under thirty years of age. These men may have had little practical experience on the drawing board or in production, and while such experience would undoubtedly benefit them in the long run, it must be admitted that they seem well able to get on without it. The circuit diagram takes the place of the drawing board, and the quarter-inch drill and soldering iron required to produce the bread-board electronic chassis take the place of the lathe and the milling machine.

Except in the relatively unusual case of the firm that has been in control engineering for some years, the manager will be faced with the extremely difficult task of controlling a group whose designs, productions, and indeed often jargon, are incomprehensible to him. In other words, not only is his mathematical and electrical background inadequate for him to understand the circuitry involved, but his own experience does not cover the products being exploited.

Management is thus faced with its own personal control problem. It can only operate by direct control on men, as opposed to the classic method of combining control on men with a degree of control on the product itself. The management of intelligent young control engineers is almost an art in itself! They are usually full of ideas and enthusiastic, quite unconcerned about vulgar economics, and often have little comprehension of the practical problems that will be met in making their designs. These gaps in their experience are inevitably due to their own lack of practical experience. Yet these are the men who are fertilizing the first-class work in electronics and precision engineering which is now being done.

Management must find the means to create conditions under which these engineers can create. As generous a development budget as is practical, and a laboratory where they can play, are two essentials, but elaborate ' showplace ' laboratories are not necessarily either effective or desirable. Fortunately, it is usually possible to develop these machines step by step: bread-board, prototype unit, prototype collection of units, and finally production. If each stage is tested and demonstrated properly, any risk that the final machine will not be satisfactory can be minimized. There must be no parallel with the ship which is at least fifty per cent complete by the time it is launched. The risk of control equipment ' sinking ' when it is ' launched ' is not inconsiderable, and a stage-by-stage practical demonstration that the system works is essential. This is an obvious means whereby management can exercise a degree of control without full comprehension.

Control engineering is a new art that is rapidly becoming a science. The bright young men of today, whom management find incomprehensible, will themselves be the managers of tomorrow. It is to be hoped that they in their turn will not themselves be overtaken by the pace of technical progress.



LETTERS to the EDITOR

No room for untidy thoughts

SIR: I have read with interest K. C. Garner's comments on the Interkama in Düsseldorf (Nov.) and find myself sympathizing with his conclusions on the lack of British enthusiasm and foresight.

I am a very recent subscriber to *Control* and am concerned with the industrial design of computers and allied electronic equipment. It would seem that from my study the British examples stand out as a collection of unrelated 'steel boxes' and are overshadowed by the American and Italian designs. Though I am not referring directly to electronic components the design lacks a conception of human values and operational details. The computer room in Britain is inhuman and the appearance of the supplementary equipment is so easily overshadowed by foreign competitors.

There is a wonderful opportunity for our electronic equipment to be brilliant if a modern design premise is called for, concerning itself with a co-ordination of specialists in a systematic design policy that is consistent with the logic of the computer and the best architectural and engineering elements. I feel that *Control* is now in a position to stimulate this design consciousness and a concern for the visual aspects which after all produce an initial impact reflecting the thought process behind the design. With the continued enlightenment of our competitors and business personnel on the Continent, there will soon be no room for untidy thoughts and we will be out of business.

Horsham, Sussex K. G. SADLER

Not just another operator

SIR: It is surprising how frequently correspondence started as a result of some article in a journal strays away from the main point of the article in question and swiftly takes the form of an academic exchange about inessentials. I believe that this has happened in the case of the correspondence arising out of "Laplace with an s",* and I trust that I may be allowed the privilege of your columns in order to return to the main point of that article which so far no writer has come forward to refute, namely the desirability of adopting what is commonly called the 's-multiplied' form of the transformation.

It has been suggested to me on a number of occasions that although the dimensional arguments are quite conclusive, they represent an academic rather than a practical point of view, and that something more concrete will need to be produced to convince the bulk of control engineers that they should change their Laplace definition to something which, however theoretically more desirable, only produces the same results. Although I consider this type of reasoning on the part of any 20th century engineer to be quite indefensible, there is nevertheless a very practical argument on purely 'transfer-function' grounds in support of the s-multiplied transform.

With what is still unfortunately amongst the undiscerning the more popular form of the Laplace integral, the function in the time domain which is the inverse of the transfer function $\bar{g}(s)$ represents the 'impulse response' of the system, i.e. the output of the system if the input has infinite magnitude for zero time at $t = 0+$. In order to determine the output for any other given input, one then can perform the operation of convolution with this highly academic and physically unrealisable impulse response. With the s-multiplied transform the inverse of the transfer function is the 'step response' of the system, i.e. the output of the system if an input of unity is suddenly applied at $t = 0$. The step response is neither academic nor physically unrealisable but is, of course, the response to suddenly applied D.C., a concept which is not only both simple and practical but which is a measurable entity which can easily be displayed visually in the laboratory. If control engineers wish to consider that dimensions are of little importance, here at any rate is a practical physical argument for universal adoption of s-multiplied transforms.

Finally, I would like to make brief comments upon what Messrs. Head and Mayo† seem to imagine are two other entirely academic and therefore unimportant matters. In support of the use of $0+$ as the lower limit of integration in the one-sided transform, let us consider a simple unit step input applied at $t = 0$. The value of this function at 0 may be considered from three points of view: it is zero at $0-$, unity at $0+$, and may be taken as $\frac{1}{2}$ at 0. It certainly does not seem to me to be either academic or unpractical to define in a given situation exactly which of the values at $t = 0$ we are considering. Again, the sort of approach which lumps 's' together with 'D' as just another operator, is one which is not only theoretically incorrect but one which can lead to very serious practical errors of calculation. Hence, I consider it essential to stress that with Laplace we are considering 'transform calculus', a calculus in which we transform the real axis of t into the complex s-plane and functions of t into functions of the complex variable $s = \sigma + j\omega$.

I find it extremely disconcerting to have to believe that in this present day and age, when advanced mathematical techniques are becoming more and more familiar to graduate engineers, matters such as those discussed in the article, 'Laplace with an s', and in the subsequent correspondence can be shrugged off as purely academic. H. GRAHAM FLEGG

R.A.F. Technical College, Henlow

* This article appeared in *Control* for July 1960, p. 105 — EDITOR

† 'Letters', *Control*, Jan. 1961, p. 75 — EDITOR

Cybernetic usage

SIR: If cybernetics is the science of control, then all control systems are cybernetic. Thus to speak of a cybernetic control system is, pedantically speaking, redundant. So far Mr. Rudkin* and I agree. But cyberneticians want more use from the adjective than can be got by dropping it as redundant. So they often use it to refer to those important control principles that have been recognized, made explicit and formalized by the science of cybernetics. I hope your readers who have noted Mr. Rudkin's intensive (and indeed extensive) attack on this shorthand find the usage as natural as we do.

United Steel Co's Ltd STAFFORD BEER

* 'Letters', December 1960.—EDITOR

How do you overcome the suspicion, fear, and disbelief of workpeople when new automatic controls are introduced? How do you recognize the different kinds of opposition that this kind of modernization evokes? How do you turn potential foes into allies? When the manager is convinced . . .

you still have to convince the operator

by **GORDON A. JONES**, *Honeywell Controls Ltd*

FEAR OF LOSING HIS JOB AND HIS IMPORTANCE IN A company is one of the most powerful emotions that can grip any man. It should be respected. This emotion is the first to develop in an operator when a management decides to put in new plant or control equipment.

Managers know that the new equipment will make a better product at less cost and effort. They are merely trying to install the best means of production. Yet the cost-reducing idea is the very one that frightens the operator, who foresees the same work being done in half the time with *half the men*. On the face of it, why should he be pleased that automatic control can often perform actions that human beings cannot?

This feeling may to some extent be allayed if managers can explain that the new equipment should enable their firm to outpace competitors at home and abroad by turning out new and better products more economically and accurately, hence encouraging more orders. Few managements can rely solely on this type of argument, however, and it may well become interminable.

I feel that gradually ' selling ' automation to operators should be done by the managers and not by outsiders, because men know their own bosses better. They may not share opinions with them, but a reassuring talk from the plant manager can do a great deal towards easing the situation during the initial stages of starting-up, and can provide engineers with the additional co-operation they require when making certain tests. These tests might strain the patience of any operator when production is in full swing. It is essential to keep him informed of any tests you are going to make while the plant is working, and to get his approval before proceeding. Otherwise he may have heart failure if he sees the roof temperature (for example) climb above the melting point of the brickwork, and *his* subsequent action may give *you* heart failure!

In the initial stages of starting-up, when the system is under manual control from the instrument, it is often of great assistance to the operator to have the gauge on the panel, which indicates the pressure being applied to the control valve, clearly marked with directional arrows, to show him which way he must turn the regulator to increase or decrease the fuel supply and so vary his furnace temperature. In fact, the more simple the controls, the more the operator appreciates it; after all, he has enough worries on his mind in keeping the furnace efficient, to maintain production at the rate expected in these days of fierce competition.

Old-timers

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Given a satisfactory criterion of performance, self-optimization may be desirable when the possible changes in conditions are not known in advance. This article introduces a selection of the different methods that have been proposed

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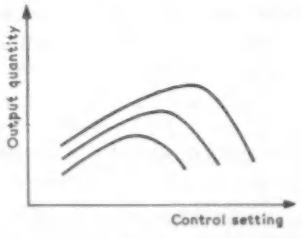
The whole subject is still very much in its infancy and the number of practical applications is relatively small. However, research is increasing rapidly, as is evidenced by the number of recent publications on the subject. No fewer than thirty papers were written on it for the Ifac Congress in Moscow. Two comprehensive lists of previous publications are given in the I.R.E. Transactions on automatic control (*1*, *2*).



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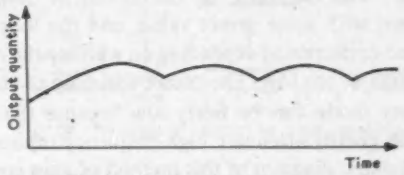

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For a given static characteristic, the output settles to a hunting oscillation about the extremum (see Fig. 2). The average value of the output is a little below the peak value and the difference is known as the hunting or search loss. The control-setting drive speed determines the hunting frequency, and this should be high compared with frequencies of variation in environmental condition, i.e. from one static characteristic to another. On the other hand, if noise in the measurement of output rate is to be filtered out, the hunting frequency must be kept as far as possible below the noise frequencies.

A variation on the above method of control is to make the control-setting drive rate proportional to the output rate divided by the drive rate. This corresponds to making the drive rate proportional to the slope of the characteristic curve. At first sight this should eliminate hunting, but difficulties arise from the ambiguous control signals which occur when the drive rate is zero.

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The correction signal is directly proportional to, or proportional to the integral of the difference between, the actual and the indicated optimum output. The latter is the same as the actual output when the output is increasing, but it remains at the highest level when the output starts to decrease. The control setting is driven at a constant rate, and the direction of drive is reversed when the correction signal exceeds a given threshold value. As with the constant-drive-rate system of output rate control, for a given static characteristic, the output settles into a hunting oscillation about the extremum.

INVARIANT-RESPONSE CONTROL

The problem is to design a control system to have a given transfer function which will be invariant for changes in the dynamic characteristics of the controlled object. Although this is a general problem, its solution is being hastened by the desire to control high-speed high-altitude aircraft throughout their flight regime. In all conditions of flight the aircraft should have a response to control commands which in the pilot's view is optimum. Since the pilot himself is adaptive, the response need not be absolutely invariant, but within reasonable bounds.

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An already familiar technique for obtaining nearly invariant response is to employ negative feedback in association with a high loop-gain. An obvious example is the use of negative feedback with high-gain d.c. amplifiers in analogue computers. This technique appears in various forms in proposals for aircraft control systems.

Another technique, which is common to a few of the

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you still have to convince the operator

by **GORDON A. JONES** *Honeywell Controls Ltd*

FEAR OF LOSING HIS JOB AND HIS IMPORTANCE IN A company is one of the most powerful emotions that can grip any man. It should be respected. This emotion is the first to develop in an operator when a management decides to put in new plant or control equipment.

Managers know that the new equipment will make a better product at less cost and effort. They are merely trying to install the best means of production. Yet the cost-reducing idea is the very one that frightens the operator, who foresees the same work being done in half the time with *half the men*. On the face of it, why should he be pleased that automatic control can often perform actions that human beings cannot?

This feeling may to some extent be allayed if managers can explain that the new equipment should enable their firm to outpace competitors at home and abroad by turning out new and better products more economically and accurately, hence encouraging more orders. Few managements can rely solely on this type of argument, however, and it may well become interminable.

I feel that gradually ' selling ' automation to operators should be done by the managers and not by outsiders, because men know their own bosses better. They may not share opinions with them, but a reassuring talk from the plant manager can do a great deal towards easing the situation during the initial stages of starting-up, and can provide engineers with the additional co-operation they require when making certain tests. These tests might strain the patience of any operator when production is in full swing. It is essential to keep him informed of any tests you are going to make while the plant is working, and to get his approval before proceeding. Otherwise he may have heart failure if he sees the roof temperature (for example) climb above the melting point of the brickwork, and *his* subsequent action may give *you* heart failure!

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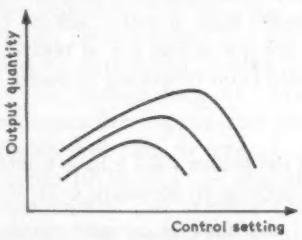

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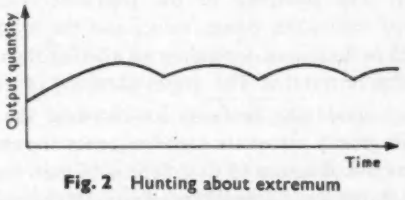

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The problem is to design a control system to have a given transfer function which will be invariant for changes in the dynamic characteristics of the controlled object. Although this is a general problem, its solution is being hastened by the desire to control high-speed high-altitude aircraft throughout their flight regime. In all conditions of flight the aircraft should have a response to control commands which in the pilot's view is optimum. Since the pilot himself is adaptive, the response need not be absolutely invariant, but within reasonable bounds.

All the control systems discussed in this section are described in reference *9*.

An already familiar technique for obtaining nearly invariant response is to employ negative feedback in association with a high loop-gain. An obvious example is the use of negative feedback with high-gain d.c. amplifiers in analogue computers. This technique appears in various forms in proposals for aircraft control systems.

Another technique, which is common to a few of the

proposed aircraft control systems, is the use of analogue models. Each analogue model is set to have the optimum response of its corresponding control loop and is carried

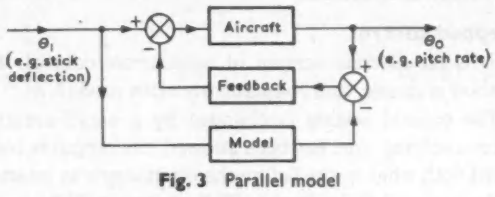

Fig. 3 Parallel model

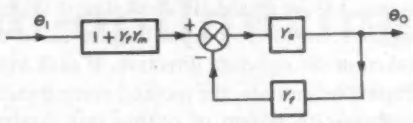

Fig. 4 Equivalent of parallel model system

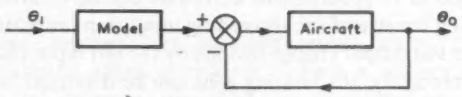

Fig. 5 Series model

in the aircraft. Control commands are then fed into the model in parallel or in series with the aircraft system.

In the parallel case, the aircraft output (e.g. rate of pitch) is measured and compared with the model output. The difference is then fed back and subtracted from the aircraft's input signal. Thus, if output is greater than it should be, input is reduced by feedback (see Fig. 3). If aircraft, feedback and model can be represented by transfer functions Y_a, Y_f and Y_m respectively, the block diagram of Fig. 3 can be represented by the equivalent diagram of Fig. 4. The overall transfer function of the system is $(1 + Y_f Y_m)Y_a/(1 + Y_f Y_a)$, and this tends to Y_m when Y_f has high gain, or to $Y_m + 1/Y_f$ when Y_a has high gain. Hence the problem reduces to one of obtaining a sufficiently high-gain feedback loop.

Fig. 5 shows how the model may be placed in series with the aircraft to obtain the same effect. Direct negative feedback is applied around the aircraft so that the overall transfer function can be written as $Y_m Y_a/(1 + Y_a)$. Thus, when Y_a has high gain the overall transfer function tends towards that of the model. Again the problem is to keep a sufficiently high loop-gain.

The uncontrolled pitch response of an aircraft can often be represented by a transfer function having two real zeros and two sets of conjugate complex poles which represent the short-period and phugoid modes of transient oscillation. The addition of some derivative feedback to the direct feedback around the aircraft gives the open-loop transfer function another real zero. The root locus diagram is sketched roughly in Fig. 6 to show how the closed-loop poles move as the loop-gain is increased. As the loop-gain is increased the closed-loop poles move in towards the real axis, that is the system becomes more stable. Unfortunately this is not the complete story, because the dynamic lags of the instruments and elevator actuator have been neglected. In particular, the actuator introduces two high-frequency complex conjugate poles which move towards the right half plane as the loop-gain is increased. A method of keeping the loop-gain as high as possible is to insert occasional pulses into the actuator and monitor the response of the actuator. The damping of the transient response is compared with some preset value, and the loop gain is increased or decreased depending on whether the damping is too high or too low. The preset damping of this high-frequency mode can be fairly low because the aircraft itself will greatly attenuate high-frequency inputs. Fig. 7 is a schematic diagram of this method of gain control.

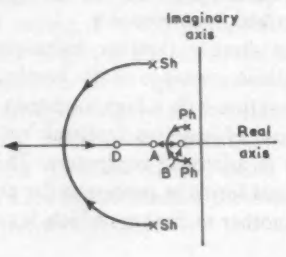

Fig. 6 Root locus diagram

Fig. 8 shows a non-linear type of aircraft control system which has very high gain when there is any appreciable

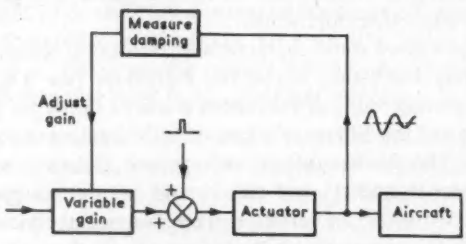

Fig. 7 Pulse method of gain adjustment

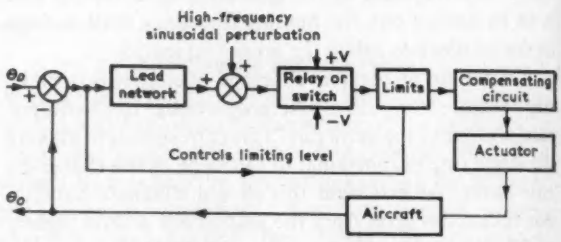

Fig. 8 Non-linear control system

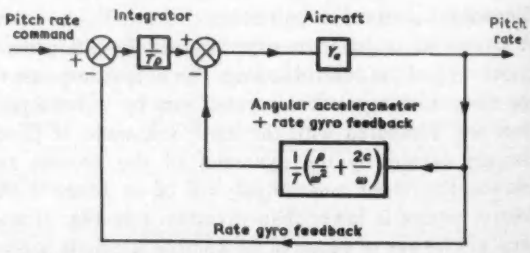

Fig. 9 Inverse of desired transfer function in feedback

error between the aircraft output and the desired output. The system would normally be associated with a series model. The control system is basically a relay system. The relay or switch circuit has an output of $\pm V$ depending on the sign of its input signal. The relay output is limited to a level which is increased when the error

signal becomes large. Stability is improved when the error is small by the addition of a high-frequency perturbing signal. The lead network and compensating circuit are included to improve the overall stability.

Another high-gain feedback method of obtaining a given overall response is to include the inverse of the desired transfer function in the feedback path. Fig. 9

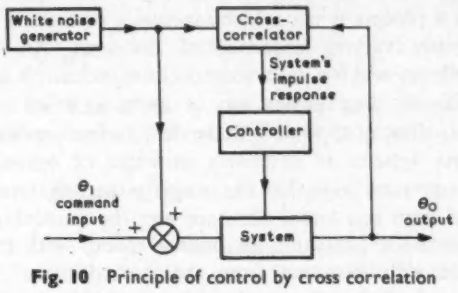

Fig. 10 Principle of control by cross correlation

shows the application of this principle to the control of aircraft pitch rate. The overall transfer function is

$$\frac{(1/Tp)Y_a}{1 + (1/Tp)Y_a[(p^2/\omega^2) + (2cp/\omega) + 1]}$$

and this tends to $\omega^2/(p^2 + 2c\omega p + \omega^2)$ when Y_a/T has high gain. The parameters c and ω can be set to desired values by adjusting the feedback gains. The problem remains of keeping the aircraft loop-gain as high as possible.

High-gain feedback methods have the advantage that no exact knowledge of the characteristics of the uncontrolled aircraft is needed at any time. If a low-gain system is used the control parameters (gains and time constants) must be adjusted to maintain the desired overall response when the aircraft characteristics change. The difficulty now is continually to monitor response characteristics so that appropriate adjustments may be made.

One method of monitoring the response characteristics of a system (assuming that the system is linear) is to superimpose random noise on the input command signal and then cross-correlate the noise with the output of the system. If the noise has a flat power spectrum over the frequency band-width of the system, the cross-correlation will give the impulse response of the system. The latter can then be compared with the desired response and appropriate adjustments made when an error exists. Fig. 10 illustrates this type of response control. The method has the merit that control over the response characteristic is unaffected by manoeuvre-command inputs, since the latter and the noise are uncorrelated. The principal objection to the method is that the necessary instrumentation is complex.

INPUT ADAPTATION

Under *Invariant-response control* above we were concerned with making a control system have some desired response. The next question is: what is the desired response? The optimum response depends upon the inputs to the system and the criterion of optimization. When some prior information about the inputs is lacking it is required that the system should optimize itself.

There must be a vast number of possible types of input for which self-optimizing systems would be appropriate, and an equally large number of methods of realizing the same. A few papers have been published which describe specific examples and three (*10*, *11*, *12*) are referred to in the bibliography. Such examples are very interesting, but we shall restrict our discussion to two more general approaches: Wiener's theory (*13*) and dynamic programming (*14*).

Self-optimization as an extension of Wiener's theory

When a signal consists of message plus noise, both of which vary randomly and are stationary in the statistical sense, the transfer function of the optimum linear filter (*13*) for separating the message out can be derived when the spectral densities of the message and the noise are known. In this case the optimum criterion is that the mean square error between message and filter output be minimum. With some extensions (*15*) the same theory can be applied to the design of a control system for following a signal which is contaminated with noise.

Consider the case of a control system which is actuated by the error between input and output. Henceforth

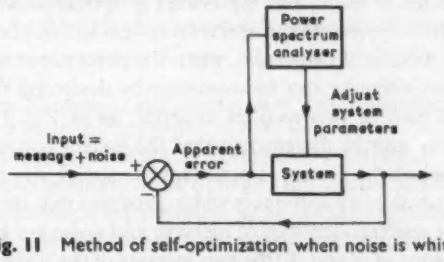

Fig. 11 Method of self-optimization when noise is white

this error will be referred to as the 'apparent error' to distinguish it from the error between message and output. When the noise is white (power spectrum with constant amplitude for all relevant frequencies) and the system is optimum in the Wiener sense, the apparent error is also white (*16*, *17*). The optimum form of transfer function for the system is determined by the form of the spectral density of the message, but the values of the optimum

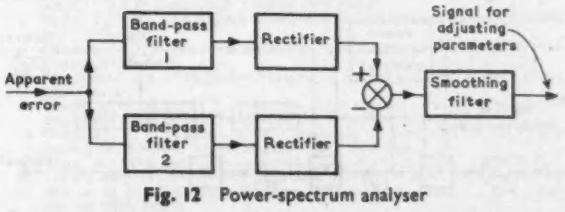

Fig. 12 Power-spectrum analyser

gains and time constants of the system depend upon the relative mean square levels of message and noise. Thus, if the form of the message spectral density is known, the system can optimize itself by adjusting its parameters until the apparent error is white (see Fig. 11). The optimum parameters will be known functions of the message-to-noise ratio, so the system parameters can be

kept in optimum relation to each other while adjustment is being made. For instance in the case given in (*17*), a gain G and a time constant T must both be adjusted, but only T need be adjusted directly if G is kept equal to $2/T^2$.

Often the power-spectrum analyser (Fig. 11) can be realized simply, as shown in Fig. 12. The apparent error signal is passed through two different band-pass filters, and the outputs are rectified, differenced and smoothed. The band-pass filters are set at such frequencies that any deviation of the system from optimum will produce from the analyser an output of the appropriate sign to adjust the parameters in the correct direction.

For physical reasons it is usually necessary to keep certain control system quantities (voltages, torques, etc.) within specified bounds. We assume here that sufficient constraint will be applied by limiting one quantity. At present the constraint can only be applied theoretically

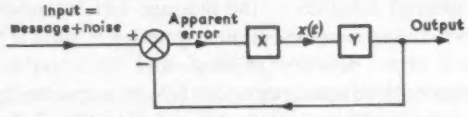

Fig. 13 Forward path in two sections

by imposing a limit on the mean square value. With such a constraint, the apparent error is no longer white when the noise is white, and the system is optimum. Also, the apparent error with the optimum system will not be white, even without a constraint, when the noise is not white.

This difficulty can be overcome by designing the forward path in two sections in series, as in Fig. 13. The sections can be designed so that the system is optimum, and when the system is optimum the signal $x(t)$ passing between the two sections is white. Provided that the forms of the spectral densities of message and noise are known, the forms of X and Y (the two sections of the system) will be fixed and the parameters can be adjusted to optimum values by applying a power-spectrum analyser to $x(t)$ instead of to the apparent error as in the former case.

There is a further difficulty, however, when a constraint must be imposed. The constraint makes the optimum system parameters into functions of a term dependent on the absolute levels of message and noise as well as of the message-to-noise ratio, i.e. the optimum parameters are

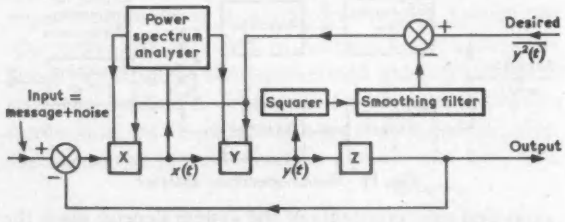

Fig. 14 Self-optimization with constraint on $\overline{y^2(t)}$

now functions of two variables. This means that two optimizing loops are required. The ratio term can be optimized as before by using the power-spectrum analyser on $x(t)$, whilst simultaneously adjusting the absolute-level term to the optimum value. The latter operation can be performed by continuously measuring the weighted mean square value of the quantity to be constrained and comparing it with the desired value (see Fig. 14).

Dynamic programming

Dynamic programming is the name given by Bellman to the mathematical theory of multi-stage decision processes. Such a process is one which involves a discrete or continuously varying sequence of decisions. An input adaptive system is a multi-stage decision process; it is continually deciding the best way of operating on its inputs.

Also directly applicable to the design of self-optimizing control systems is Bellman's principle of optimality: 'An optimum policy has the property that whatever the initial state and initial decisions are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision'. The basis of Bellman's mathematical technique, which can be applied to the design of self-optimizing control systems, is given in Chapter IX of his book (*14*). The method of design will be illustrated by working through an example given in a paper by Merriam (*18*). It must be noted, however, that there are many other workers in this field besides Bellman and Merriam.

Suppose that we have a physical process with input $\theta_1(t)$ and output $\theta_0(t)$. Let the cost function be:

$$\int_t^{t+T} [\gamma(\sigma)\{\theta_D(\sigma) - \theta_0(\sigma)\}^2 + \theta_1^2(\sigma)]\,d\sigma = \int_t^{t+T} E(\sigma)\,d\sigma,$$

where $\theta_D(t)$ is the desired output and γ is a Lagrange multiplier. t represents the present time. Nothing can be done about the past, so the cost function only applies to a future time T. γ is included in the expression to impose a constraint on θ_1. This is done in the same way that a constraint was applied in the theory behind the systems we discussed above under *Self-optimization as an extension of Wiener's theory*. Suppose further that the process consists mathematically of an integration with time-variable gain, i.e. it can be represented by the equation $\theta_0'(t) = b(t)\,\theta_1(t)$ where the prime denotes differentiation with respect to the argument t. The problem now is to find a $\theta_1(t)$ which will minimize the cost function. The functions $\gamma(t)$, $b(t)$ and $\theta_D(t)$ are assumed to be known functions of time, and T is a given constant interval of time. Write the minimum cost function as

$$f(\theta_0, t) = \theta_1\overset{\text{min.}}{[t, t+T]} \int_t^{t+T} E(\sigma)\,d\sigma$$

where $\theta_1\overset{\text{min.}}{[t, t+T]}$ denotes minimum with respect to θ_1 over the time between t and $t+T$.

Now if μ is some time such that $t \leqslant \mu \leqslant t+T$,

$$\begin{aligned} f(\theta_0, \mu) &= \theta_1\overset{\text{min.}}{[\mu, t+T]} \int_\mu^{t+T} E(\sigma)\,d\sigma \\ &= \theta_1\overset{\text{min.}}{[\mu, t+T]} \left[\int_\mu^{\mu+S} E(\sigma)\,d\sigma + \int_{\mu+S}^{t+T} E(\sigma)\,d\sigma \right] \\ &= \theta_1\overset{\text{min.}}{[\mu, t+T]} \left[\int_\mu^{\mu+S} E(\sigma)\,d\sigma + f(\theta_0, \mu+S) \right] \end{aligned}$$

The last expression is correct, since we apply the optimal policy throughout, so that the integral from $\mu + S$ must be the minimum cost function starting from $\mu + S$.

Now under the appropriate assumptions of continuity, when S approaches zero, we can write

$$\int_{\mu}^{\mu+S} E(\sigma)\,\mathrm{d}\sigma = S\,E(\mu), \quad \theta_0(\mu + S) = \theta_0(\mu) + S\frac{\mathrm{d}\theta_0(\mu)}{\mathrm{d}\mu}$$

and $$f(\theta_0, \mu + S) = f(\theta_0, \mu) + S\frac{\mathrm{d}\theta_0}{\mathrm{d}\mu}\frac{\partial f}{\partial \theta_0} + S\frac{\partial f}{\partial \mu},$$

using the first terms of the Taylor expansion in the second equation. Substituting back into the original equation

$$f(\theta_0, \mu) = \theta_1[\mu, \overset{\text{min.}}{\mu} + S]\left[S\,E(\mu) + f(\theta_0, \mu) + S\frac{\mathrm{d}\theta_0}{\mathrm{d}\mu}\frac{\partial f}{\partial \theta_0} + S\frac{\partial f}{\partial \mu}\right]$$

or $$0 = \overset{\text{min.}}{\theta_1(\mu)}\left[E(\mu) + \frac{\mathrm{d}\theta_0}{\mathrm{d}\mu}\frac{\partial f}{\partial \theta_0} + \frac{\partial f}{\partial \mu}\right], \text{ since } S \to 0.$$

The process equation says that $\dfrac{\mathrm{d}\theta_0}{\mathrm{d}\mu} = b(\mu)\theta_1(\mu)$

Thus $$0 = \overset{\text{min.}}{\theta_1(\mu)}\left[\gamma(\mu)\{\theta_D(\mu) - \theta_0(\mu)\}^2 + \theta_1^2(\mu) + b(\mu)\theta_1(\mu)\frac{\partial f}{\partial \theta_0} + \frac{\partial f}{\partial \mu}\right],$$

when the substitution for $E(\mu)$ is also made. Assuming that a minimum exists, and is the only point of zero slope of the above function, the minimum is determined by differentiating with respect to $\theta_1(\mu)$.

$$2\theta_1(\mu) + b(\mu)\frac{\partial f}{\partial \theta_0} = 0$$

Thus the optimum $\theta_1(t)$ is given by $\theta_1(t) = -\frac{1}{2}b(t)\dfrac{\partial f}{\partial \theta_0}$

Substituting back into the differential equation for $f(\theta_0, \mu)$ gives $\gamma(\mu)\{\theta_D(\mu) - \theta_0(\mu)\}^2 - \left\{\dfrac{b(\mu)}{2}\dfrac{\partial f}{\partial \theta_0}\right\}^2 + \dfrac{\partial f}{\partial \mu} = 0.$

The solution of this equation can be written in the form

$$f(\theta_0, \mu) = K_0(\mu) + K_1(\mu)\theta_0 + K_2(\mu)\theta_0^2.$$

Thus $$\frac{\partial f}{\partial \theta_0} = K_1(\mu) + 2K_2(\mu)\theta_0$$

$$\frac{\partial f}{\partial \mu} = K_0'(\mu) + K_1'(\mu)\theta_0 + K_2'(\mu)\theta_0^2$$

Substituting in the differential equation for $f(\theta_0, \mu)$ gives

$$[\gamma(\mu)\theta_D^2(\mu) - \{b^2(\mu)/4\}K_1^2(\mu) + K_0'(\mu)] + [-2\gamma(\mu)\,\theta_D(\mu) - b^2(\mu)K_1(\mu)K_2(\mu) + K_1'(\mu)]\,\theta_0(\mu) + [\gamma(\mu) - b^2(\mu)K_2^2(\mu) + K_2'(\mu)]\,\theta_0^2(\mu) = 0$$

For this to be true for all $\theta_0(\mu)$, each expression in square brackets must be identically zero, i.e.

$$K_0'(\mu) = -\gamma(\mu)\,\theta_D^2(\mu) + \{b^2(\mu)/4\}K_1^2(\mu)$$

$$K_1'(\mu) = 2\gamma(\mu)\,\theta_D(\mu) + b^2(\mu)K_1(\mu)K_2(\mu)$$

$$K_2'(\mu) = -\gamma(\mu) + b^2(\mu)K_2^2(\mu).$$

Now $f(\theta_0, t + T) = 0$ since $\int_{t+T}^{t+T} = 0$. Also this must be true for all $\theta_0(t + T)$. Therefore from the equation for $f(\theta_0, \mu)$, we have the boundary conditions $K_0(t + T) = K_1(t + T) = K_2(t + T) = 0$. Since the optimum

$$\theta_1(t) = -\frac{b(t)}{2}\frac{\partial f}{\partial \theta_0} = -\frac{b(t)}{2}K_1(t) - b(t)K_2(t)\theta_0(t),$$

only $K_1(t)$ and $K_2(t)$ need be derived in order to realize the optimum control law.

Since the boundary conditions for K_1 and K_2 are given at time $t + T$, the values of K_1 and K_2 at time t must be found by solving the equations repetitively with a high-speed computer. The general arrangement for the self-optimizing system is shown in Fig. 15.

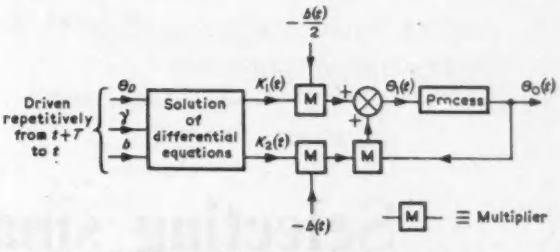

Fig. 15 Dynamic programming realization

Notice the following two points regarding this system:

a The desired output θ_D must be known for a future period of time T.

b The controller is optimum for all θ_0: this implies that it will be optimum in the presence of load disturbances.

The above example is comparatively simple. Other cases are generally more difficult, and the solutions have yet to be found for the majority of possible applications.

This last section has been mostly mathematics. I give no apology because it is a mathematical subject. Nevertheless I hope that some readers will try their own hands at dynamic programming because it is rapidly becoming an important synthesis procedure for self-optimizing control systems.

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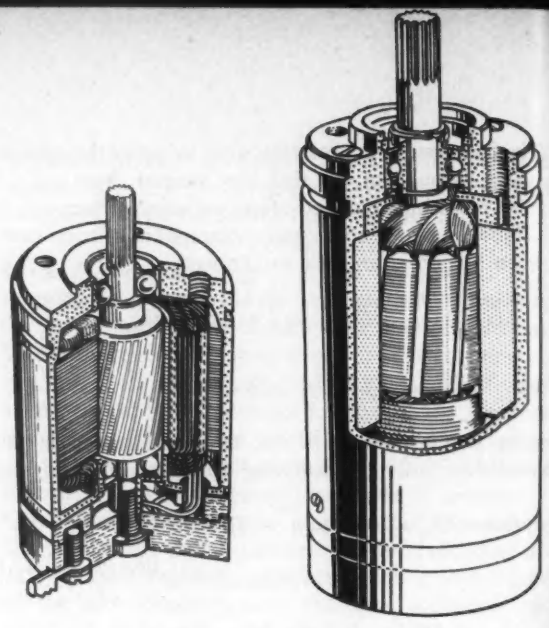
PART 2



As usual in engineering, compromise is often necessary in choosing servo-motors. Rapid selection is made easier by this design approach

Selecting small servo-motors

by **T. B. WEARDEN** B.Sc.(Tech.), A.M.I.E.E.
Vactric (Control Equipment) Ltd

Last month we discussed the relative merits of a.c. and d.c. systems, the question of temperature and rating, the nature of the design approach, and load power.

Load acceleration

If a motor:gear-box:load system is energized by a step voltage the velocity *v.* time run-up curve will have the general form shown in Fig. 4. As speed increases, so does the proportion of overall torque needed to overcome viscous effects; acceleration therefore decreases if the load torque is constant. However, in designing a continuous servo-mechanism, of the general type shown in Fig. 5, this curve has little value because the motor control voltage is continuously modified by the error signal and its derivatives. In considering the acceleration requirements of such a system it is therefore convenient and sufficient to take the parameter *starting acceleration* as a guide to the first selection of a suitable motor.

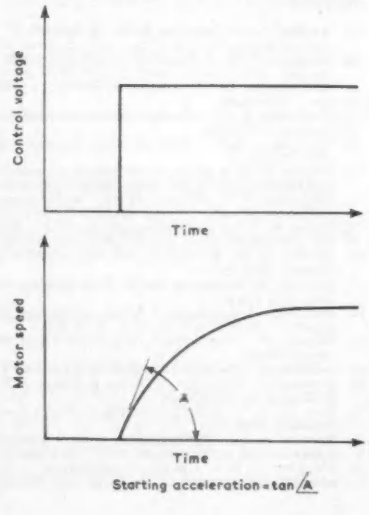


Fig. 4 Form of velocity run-up curve for step control voltage

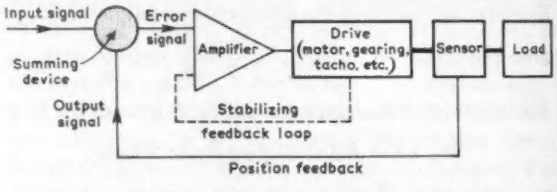


Fig. 5 Schematic form of positional servo-mechanism

When the load moment of inertia, I_L, is negligible compared with that of the motor, starting acceleration is expressed simply as

$$\alpha_{L(\text{start})} = \frac{1}{N}\alpha_{M(\text{start})} = \frac{1}{N}\cdot\frac{T_{M(\text{stall})}g}{I_M} \text{ rad/s}^2$$

and in Table II typical values of starting acceleration, $\alpha_{M(\text{stall})}$, for a range of small International-Frame-Size motors are given. However, when a load of finite moment of inertia is to be accelerated the parameter *motor starting acceleration* has little significance in selecting a suitable servo-motor to satisfy given load-stalling acceleration conditions.

It has been shown previously (*1*) that for a motor:

gear-box:load system the starting acceleration equation is

$$\alpha_{L(\text{start})} = \frac{NgT_{M(\text{stall})}}{I_L/\eta + I_M N^2} \text{ rad/s}^2$$

and also that $\alpha_{L(\text{start})}$ is a maximum when

$$N = N_{(\text{optimum})} = \left(\frac{I_L}{I_M}\cdot\frac{1}{\eta}\right)^{\frac{1}{2}}$$

Then

$$\alpha_{L(\text{start})(\text{max})} = \frac{\left(\frac{I_L}{I_M}\cdot\frac{1}{\eta}\right)^{\frac{1}{2}} gT_{M(\text{stall})}}{2I_L/\eta} \text{ rad/s}^2$$

or, rearranging,

$$4\alpha^2_{L(\text{max})(\text{start})}\,\frac{I_L}{\eta} = \frac{T^2_{M(\text{stall})}\,g^2}{I_M}$$

The left-hand side of this last equation is expressed entirely in terms of load parameters, and the right-hand side is essentially a motor parameter. A powerful technique for servo-motor selection is therefore available, since, if values of $(T_{M(\text{stall})}g)^2/I_M$ of servo-motors are known, then a suitable motor for driving a load inertia I_L with acceleration α_L can immediately be selected.

(In the above derivation stiction and friction have been neglected. The general case when frictional effects are taken into account has been discussed (*2*) but in a large number of small servo-motor applications the neglect of friction at this stage is justified.)

The parameter $(T_{M(\text{stall})}g)^2/I_M$, if expressed directly in c.g.s. units, has very large values. However, a convenient expression in the strange units W/s may be derived, with the physical concept of ' rate of power build-up ' since

$$\frac{\text{torque}^2\,(\text{dyne}^2\,\text{cm}^2)}{\text{inertia}\,(\text{g cm}^2)}$$

$$= \text{torque (dyne cm)} \times \text{acceleration (rad/s}^2\text{)}$$

$$= \frac{\text{torque (dyne cm)} \times \text{velocity (rad/s)}}{\text{time (s)}}$$

$$= \frac{\text{power (erg/s)}}{\text{time (s)}}$$

$$= \text{(W/s)} \times 10^{-7}$$

TABLE II

Values of $\left(\frac{T_{M(\text{stall})}g}{I_M}\right)$, *i.e. stall acceleration, and* ψ_M *for a range of small a.c. and d.c. International-Frame-Size servo-motors*

MOTOR TYPE	$\frac{T_{M(\text{stall})}g}{I_M}$ (rad/s²)	ψ_M (W/s)
a.c.		
07	59 × 10³	52
10	41 × 10³	85
11	41 × 10³	154
15	29 × 10³	300
18	40 × 10³	660
d.c.		
08	41 × 10³	500
11	38 × 10³	1160
15	38 × 10³	2150
18	36 × 10³	3860

NOMENCLATURE

Torque (gf cm)
- T_M = Motor output torque
- $T_{M(\text{stall})}$ = Motor stalling torque

Speed (rad/s)
- ω_M = Angular velocity of motor
- ω_L = Angular velocity of load

Acceleration (rad/s²)
- α_M = Angular acceleration of motor
- α_L = Angular acceleration of load

Inertia (g cm²)
- I_M = Motor inertia
- I_L = Load inertia

Power (W)
- W_M = Motor output power
- W_L = Load driving power

Other motor parameters

$$\psi_M = \frac{(T_{M(\text{stall})}g)^2}{I_M} \times 10^{-7} \text{ W/s}$$

Efficiency
- η = Gear-head torque efficiency

Gear ratio
- N = Gear-head ratio, where $N > 1$ for step-down ratio

Constants
- $K_{L(n)}$ = Generalized load running torque constant, when $T_L(\beta) = \Sigma K_{L(n)}\omega_L^n$
- g = Gravitational acceleration (cm/s²)

Symbols such as ω_L', T_M' etc. indicate a defined or particular value of the generalized parameter.

It is convenient to introduce a motor parameter ψ_M, defined by:

$$\psi_M = \frac{(T_{M(\text{stall})}g)^2}{I_M} \times 10^{-7} \text{ W/s}$$

Curves have been drawn (Fig. 6) enabling one to plot the minimum permissible value of ψ_M for a wide range of values of $\alpha_{L(\text{start})}$ and I_L. The procedure for selecting a servo-motor using these curves is:

1 Plot vertical for η.

2 Plot horizontal at point of intersection with appropriate curve for I_L.

3 Minimum ψ_M operating point for motor is then at point of intersection with vertical for load acceleration.

4 In general, any motor whose ψ_M curve is above this operating point will be capable of meeting the acceleration requirements providing a suitable gear ratio is employed.

Gear ratio

The curves of Fig. 6 assume optimum gear ratio,

$$N_{(\text{optimum})} = \left(\frac{I_L}{I_M}\cdot\frac{1}{\eta}\right)^{\frac{1}{2}}$$

When the ratio has to be greater or less than $N_{(\text{optimum})}$ in order to satisfy some other aspect of design (for ex-

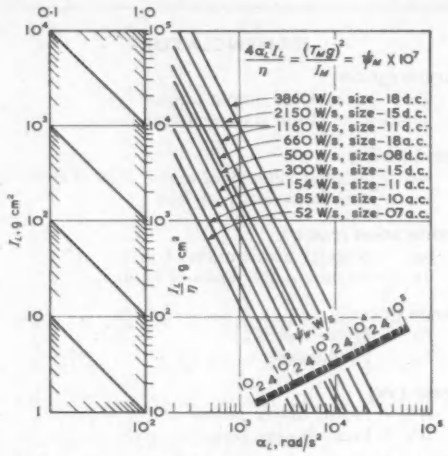


Fig. 6 Servo-motor selection on the basis of load-stalling acceleration

ample maximum load speed) then the acceleration will be less than maximum.

If a starting acceleration $\alpha_{L(\text{start})}$ is achieved with a ratio N', such that

$$\frac{N'}{N_{(\text{optimum})}} = S$$

then

$$\alpha'_{L(\text{start})} = \frac{N'\, g\, T_{M(\text{stall})}}{\frac{I_L}{\eta} + I_M N'^2}$$

$$= \frac{S\left(\frac{I_L}{I_M}\frac{1}{\eta}\right)^{\frac{1}{2}} g T_{M(\text{stall})}}{\frac{I_L}{\eta}(1 + S^2)}$$

$$= \alpha_{L(\text{start})(\text{max})} \left(\frac{2S}{1 + S^2}\right)$$

thus if Fig. 6 is used to determine $\alpha_{L(\text{start})(\text{max})}$ for a system, given η, I_L and ψ_M for a servo-motor selected by other criteria, the actual starting acceleration that will be achieved, $\alpha'_{L(\text{start})}$ can be calculated from

$$\frac{\alpha_{L(\text{start})}}{\alpha_{L(\text{start})(\text{max})}} = \frac{2S}{1 = S^2}$$

where

$$S = \frac{N'}{N_{(\text{optimum})}}$$

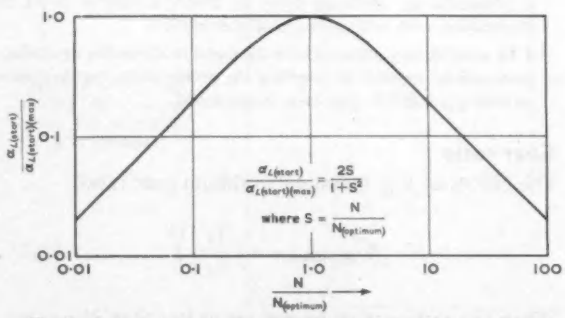


Fig. 7 Calculation of starting acceleration when optimum gear ratio is not used

In Fig. 7 values of $2S/(1 + S^2)$ are plotted for a range of values of S and the effects on load-stalling acceleration of using a gear ratio other than optimum can readily be established from this curve. An example of this technique is worked in the appendix to illustrate the use of these various curves.

Merits of method

As in most engineering design, a compromise solution is often necessary, the extent of the compromise being determined by system design requirements. However, it is suggested that the design approach discussed, and the use of the curves plotted in Figs. 3, 6 and 7 (in conjunction with motor manufacturer's characteristics) will permit the performance of small servo-motors in a wide range of systems to be readily estimated, and will help in the rapid selection of components suitable for particular applications.

APPENDIX

Example illustrating the selection of a servo-motor on the basis of load-stall acceleration.

A load with moment of inertia 100 g cm² has to have a minimum starting acceleration of 1300 rad/s². What is the smallest a.c. 400-c/s servo-motor that may be employed,

1 If a special gear-box may be designed,

2 If a standard-rate International-Frame-Size gear-head is to be employed?

(Assume that $\eta = 0{\cdot}8$ in each case).

From Fig. 6 it is seen that a motor is required with $\psi_M > 85$ W/s. Two motors will therefore be considered, size-10 and size-11.

For size-10 motor ($I_M = 0{\cdot}5$ g cm²):

Optimum gear ratio for max. acc'n. is

$$N_{(\text{optimum})} = \left(\frac{100}{0{\cdot}5} \times \frac{1}{0{\cdot}8}\right)^{\frac{1}{2}} = 15{\cdot}8 : 1$$

and from Fig. 6 is is seen that, if this motor is employed with optimum gear ratio, then

$\alpha_{L(\text{stall})} = 1300$ rad/s² which just meets the specification.

A size-10 motor may therefore be used in this application if a special gear ratio of 15·8 : 1 is employed, but the required acceleration will not be achieved if a standard ratio is employed

For size-11 motor ($I_M = 1{\cdot}0$ g cm²).

Optimum gear ratio for max. acc'n. is

$$N_{(\text{optimum})} = \left(\frac{100}{1{\cdot}0} \times \frac{1}{0{\cdot}8}\right)^{\frac{1}{2}} = 11{\cdot}2 : 1$$

and from Fig. 6 it is seen that if this motor is employed with optimum gear ratio

$$\alpha_{L(\text{start})(\text{max})} = 1700 \text{ rad/s}^2.$$

and the permissible acceleration reduction factor is then

$$\frac{\alpha_{L(\text{start})}}{\alpha_{L(\text{start})(\text{max})}} = \frac{1300}{1700} = 0{\cdot}77$$

therefore, from Fig. 7, the spread of permissible gear ratio is

$$0{\cdot}48 < \frac{N}{N_{(\text{optimum})}} < 2{\cdot}1$$

and the range of possible ratios with which the acc'n. spec. may be achieved is

$$(11{\cdot}2 \times 0{\cdot}48) < N < (11{\cdot}2 \times 2{\cdot}1)$$

i.e. $$5{\cdot}4 < N < 23{\cdot}5$$

Either of the two standard ratios 10 : 1 or 20 : 1 may therefore be employed if a size-11 motor is selected for this application.

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2. West, J. C. and Leonard, J. L.: 'The necessary torque requirements for a servo-motor', *Journ. Sci. Insts.*, 1955 (Jan.).

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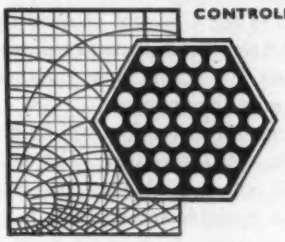


Need for mass-flow control complicates the choice of blower drive, and no one solution answers every case

Control of blowers

by **G. H. INGLIS** B.Sc., A.M.I.Mech.E.

THE GAS-COOLED REACTOR HAS SEVERAL COMPONENTS which are conventional in principle, but because of special requirements peculiar to the nuclear field have required extensive development in recent years. The gas blowers are in this category, and although mechanical design is tending to become standardized, there still remain several controversial features regarding blower drive and the method of mass-flow control in the reactor units. These features will be discussed below and designs in present British gas-cooled reactors will be compared.

The term 'blower' is in a way a misnomer, and a more accurate description is perhaps 'pressurized fan', since it is required to handle a comparatively large throughput of gas and increase its pressure by a very small ratio. Pressure ratios of approximately 1·05 are usual, and a single unit may handle from 1000–3000 lb/s of carbon dioxide at pressures of 150–300 lbf/in² and temperatures of about 200°C. Compared with that of conventional blowers and compressors, then, the duty is unusual in that the gas is not at atmospheric conditions at inlet, and the temperature is comparatively high. Only in the gas turbine field have conditions at all similar been encountered, and it is from such practice that development has proceeded. The terms 'circulators' and 'compressors' are sometimes used in the nuclear field, but 'blower' is probably most appropriate in terms of mechanical design and duty, and is used here.

AXIAL OR CENTRIFUGAL?

A typical characteristic for a blower for a gas-cooled reactor is shown in Fig. 1. Both axial and centrifugal designs are in use, but there is little significant difference between the characteristics of the types. Normally the speed lines of the axial blower would tend to be a little steeper, and perhaps the region between maximum efficiency and surge more restricted; however, with the types of axial blading now in use, these differences often hardly exist. The characteristics should ideally be steep enough for operation in parallel not to present any difficulties—in other words, a small change in pressure ratio should not correspond to a large change in mass flow if stable operation is to be achieved.

The overall efficiency of typical blowers, measured between inlet and outlet flanges, is about 80%. There is not much difference between axial and centrifugal

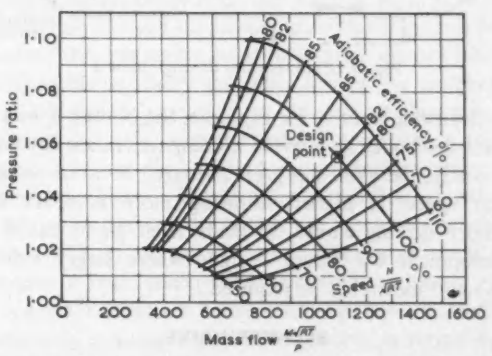


Fig. 1 Typical characteristic of blower for gas-cooled reactor

blowers with regard to efficiency. Normally the axial blower can be more efficient if inlet losses are kept low and a high-efficiency diffuser is employed. This is necessary because, as the duty quoted above can be achieved easily by a single stage of blading, external losses have a significant effect on the overall efficiency.

The choice between axial and centrifugal blowers for a particular project will not usually depend upon aerodynamic considerations, since, as indicated above, there is little to choose between them in performance or

efficiency. Mechanical problems tend to predominate, and the design will be influenced mainly by the requirement for gas-tight enclosure, the form of station layout, and possibly also by any limitations of speed imposed by the type of drive.

A centrifugal design inevitably leads to a casing of large diameter, and difficulties arise in designing a rigid structure which will not distort under pressure and temperature and cause gas leakage at joints and seals. Such experience on the centrifugal blowers at Calder Hall led to the adoption at Bradwell of an axial design with a cylindrical casing having only a single circular joint sealing to atmosphere. A cross-section through the unit is shown in Fig. 2.

With regard to station layout, the centrifugal design will normally introduce a 90° change of direction in gas flow in the horizontal plane, preventing a compact layout. At Hunterston the enclosure and layout problems have been solved by mounting the blower vertically in the lower end of the boiler shell. This may be a costly solution when the additional length of large diameter shell is allowed for; also, the vertical shaft tends to eliminate high rotational speeds. With the axial design, the duct layout may be conveniently arranged in one vertical plane, easing thermal expansion problems. In

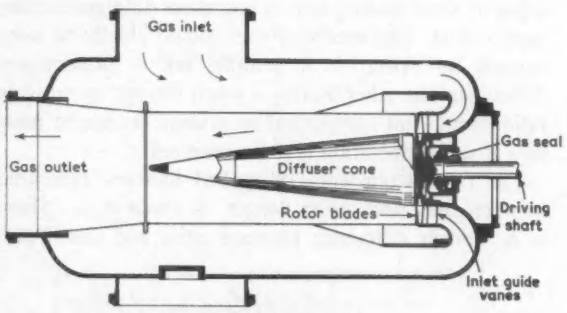


Fig. 2 Cross-section through blower

the Bradwell reactor, for example, the blower is located under the boiler to provide a compact station layout.

Finally, the axial design is favoured because its optimum speed is higher, allowing more compact and cheaper driving units. It lends itself more easily to development for future designs where larger volume flows will inevitably be required.

BLOWER DRIVE

The primary requirements for blower units are reliability and freedom from maintenance. Outages mean a substantial reduction in reactor output, and if more than a certain proportion of the total number of units is out of action, the reactor may have to be shut down. With this requirement in mind, the selection of the driving unit will be influenced mainly by the maximum power and speed required; however, the problem of mass-flow control introduces complications. Variation of load on the power station is best met by change of gas mass-flow whilst keeping gas temperatures approximately constant. Apart from maintaining highest efficiency, this method avoids unnecessary thermal cycling of the plant, in particular of the fuel elements, on which its accumulated effects might limit life. Whilst it is true that the stations in the U.K. are planned for base-load operation, nevertheless load demand will normally vary between 70% and 100%, and flow variation over this range is a minimum requirement.

In most stations, the mass flow will be controlled by means of blower speed variation. The table on page 97 gives details of the blowers on existing U.K. designs. Once a variable-speed drive is accepted in principle, it is desirable to have as wide a range as possible in order to provide flexibility for starting-up and part-load operation, so that undue restrictions will not be placed upon operating staff. If the blowers are able to operate at low speeds then gas temperatures may be increased more rapidly during starting-up, so that normal steam pressures and temperatures can be achieved to facilitate loading of the turbo-alternators. Usually the steam output from a reactor unit is divided between two or three main turbo-alternators, and it is desirable operationally to load these in sequence, rather than increase output simultaneously on all machines. As it happens, most of the acceptable methods of speed control will allow a speed range of 5/1 or even 10/1 just as easily as a smaller range. Mass flow is approximately proportional to speed, and a wide power-range can therefore be covered without dropping gas-temperatures. Another advantage of speed control is that a small margin of overspeed may be provided to allow for errors in prediction of circuit resistance, so that guaranteed output can be achieved. This margin may be between 5% and 10% above design speed.

The available blower drives for typical conditions can be broadly classified as follows, where speed variation is required:

1 A.C. squirrel-cage motors, variable frequency supply
2 A.C. squirrel-cage motors, fluid couplings
3 D.C. motors, voltage control from rectifiers or motor generator sets
4 Steam turbines.

As stressed previously, reliability is the outstanding consideration. A squirrel-cage motor, in conjunction with variable-frequency supply or a fluid coupling, is an attractive driving unit for the blowers. The squirrel-cage motor is simple and rugged in construction, and it has an inherent reliability which is difficult to better. Furthermore, it is cheap in comparison with other types of motor, and is usually suitable for the output required since motors of several thousand horse-power are common.

VARIABLE FREQUENCY

At Bradwell, Hinkley Point and Latina (Italy), a variable-frequency supply is obtained from auxiliary turbo-alternators. On the U.K. stations, the six blowers on each reactor are supplied from one machine. A third turbo-alternator is provided as a spare to allow for

maintenance on one of the other machines. At Latina, which is a single-reactor station, the six blowers are supplied from two machines operating in parallel. Each is designed for 50% of the maximum total input to the blowers, which allows a station output of about 80% if one machine is shut down (power input to blowers varies as the cube of mass flow).

The only criticism which might be levelled at turbo-electric drive is that all blowers on a reactor may be connected to a single turbo-alternator, and a fault on this machine could cause the reactor to trip. In the systems mentioned above, a second machine can be synchronized and take over the load if the fault is such that time is available for this. The arrangement at Latina is therefore better in this respect, for the second machine will usually be operating in parallel most of the time, and therefore load-shedding to 80% will be the loss in the event of one turbo-alternator tripping out unexpectedly.

On this question of overall availability, the important factor is that the design features of these auxiliary turbo-alternators, machines of 10–30 MW output operating on moderate steam conditions, are such that many years of experience on similar machines should ensure reliable, trouble-free operation. With regard to the electrical part of the system, availability may be better on the turbo-electric drive than where the motors are supplied from the station auxiliary system and are therefore part of a large network linked to the grid. Incidents should be less on the isolated system if simplicity is used to advantage in the design.

The control of the turbo-electric drive is simple. The speed of the auxiliary turbo-alternator is varied in the normal way by governor control, and the speed of all the blowers is set by the frequency of supply from the alternator. When operating blowers in parallel on a reactor, the speeds of all units should be very nearly identical. If one unit differs from the others by more than a certain amount, depending upon the characteristic, then it may 'surge' (stalling, or reversing flow) causing a sharp reduction in mass flow through the reactor. Usually the design point and the form of the characteristic are selected to ensure that blower speeds must be widely out of step for this to occur. A second and more important reason for maintaining equal speeds is that gas temperatures on individual circuits at inlet to the reactor should not vary by more than a few degrees, the tolerance depending upon the degree of mixing of the gas in the reactor vessel to make temperature distribution more nearly uniform at the inlet to the core.

With frequency control, the speeds of all the blower units are always identical, unless the supply to one unit fails. Since it is not possible to have small variations of speed between individual blowers, care must be taken in designing the pressure circuits not to introduce differences in circuit resistance which could cause an appreciable difference in mass flow between circuits. A further possibility is that there may be small differences in the performance of blowers constructed to the same nominal design. With careful design these two difficulties can be overcome, so that with blowers operating at identical speeds, differences in reactor gas inlet temperature between circuits will hardly be detectable within the limits of measuring error. Therefore the trimming of speeds on individual blowers will not be required.

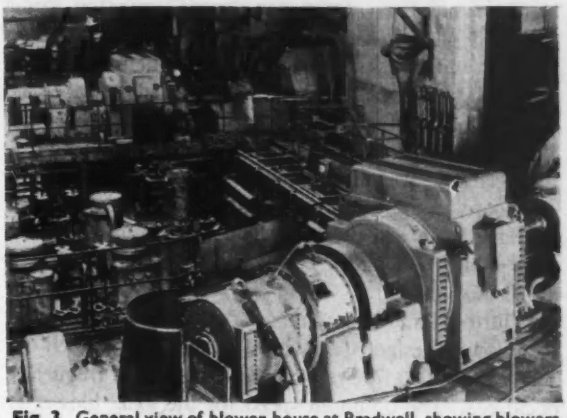


Fig. 3 General view of blower house at Bradwell, showing blowers, blower motors, and pony motors

At first glance the cost of the turbo-electric system would appear to be appreciably higher than that of other types of drive. Of the total, the cost of the auxiliary turbo-alternators obviously forms a significant part. However, with electrical drives the power for the blowers has to be generated on the main turbo-alternators if not on auxiliary machines, and the important factor is the difference in cost between the two methods. Under certain conditions the additional cost is not appreciable, though obviously spare auxiliary machines increase the investment as an insurance for availability.

When the auxiliary machines are of the condensing type (which are larger), as on the stations shown in the table on page 97, then the reduction in output and in steam flow on the main turbo-generators eases the exhaust problems. The steam volume flow at exhaust is the factor limiting the output per machine, and therefore provision of auxiliary machines may allow the number of main turbo-alternators to be reduced.

A price comparison between blower drives is therefore necessarily a complicated investigation covering many items of equipment in the nuclear power station. Efficiency also must be considered, and here the turbo-electric drive is attractive, maintaining high efficiency down to quite low speeds. At Bradwell, turbo-electric drive was selected after consideration of the points mentioned above, because it offered the least technical uncertainty of the many alternatives. On all components there existed considerable experience in the power range required, and a reasonably firm assessment of reliability and availability could be made. In these respects, therefore, it also offered the least economic uncertainty.

FLUID COUPLINGS

The squirrel-cage induction motor may also be employed to provide a variable-speed drive through a fluid couplings, as at Berkeley power station. Here the motors are supplied from the main generating units and operated at fixed frequency, speed variation being obtained on each blower unit by fluid coupling. This method suffers the disadvantage of poor efficiency at part load, the efficiency being approximately equal to the ratio of blower speed to motor speed. On a base-load station this feature may not be so serious, but some loss of efficiency even at design output is incurred if an overspeed margin is required. A 10% speed margin would involve a coupling efficiency at design speed of only about 87%, and a power loss of about 4 MW on a 300 MW station.

A further limitation of a fixed-frequency supply is that the blower design speed must correspond closely to 3000, 1500, 1000, 750 rev/min or lower with a frequency of 50 c/s. The optimum speed for the axial blower is usually in the range of 2000–3000 rev/min and the choice of 3000 or 1500 rev/min may impose problems. For a centrifugal blower the optimum speed is lower, usually about 1000 rev/min, and the restriction is not so important.

Fluid couplings have not previously been built for the powers and speeds necessary for reactor blowers. The Berkeley couplings are the largest built for 3000 rev/min and a double unit is necessary. Several of the units have now been successfully tested. Further development would be needed for couplings suitable for blowers on a 500-MW station.

D.C. motors

D.C. motors have been used at Calder Hall and Chapelcross, and have been chosen for Hunterston. It is difficult to achieve large outputs or high speeds with this form of drive. An upper limit of about 2000 bhp at 1000 rev/min does not allow much flexibility in choice of blower design. Hunterston employs tandem motors for conditions not much more arduous than the above. This type of drive is not suitable in most cases for axial blowers, and all proposals up to the present have been for centrifugal designs. The main disadvantage of d.c. motors is the maintenance required on the brush-gear. When commutator design is being stretched to the limit. it is not easy to avoid high brush wear. Although maintenance of this type does not necessarily mean a low availability, it is an undesirable feature in comparison with what obtains on other forms of drive.

Turbine drive

An obvious solution to the problem of driving the blowers is to use some of the steam generated by the reactor to drive a turbine directly coupled to the blower. It is equally obvious that the possible attractions of simplicity and flexible speed control are not obtained without some restrictions or disadvantages, otherwise steam-turbine drive would have been proposed in more designs. At present the stations for Tokai-Mura (Japan) and Dungeness are the only firm proposals incorporating turbine drive.

At low powers, say about 2000 bhp, the steam turbine is not attractive; its optimum speed is high, and usually much higher than that of the blower. The overall efficiency will therefore be low unless a gear-box is included in the drive. In any case, it will be difficult to equal the efficiency of other types of drive at these low powers because of the poor internal efficiency of the turbine. At higher powers, the turbine becomes more attractive, as problems develop on the electrical forms of drive. The design of switch-gear and motors to meet all requirements becomes increasingly difficult at unit powers above 6000 bhp, and it is in this region that the turbine begins to compare favourably. The main attractions are low capital cost, flexible choice of speed, and simple speed control.

The design of turbine will depend largely upon the steam cycle proposed for the station. With the dual-pressure steam cycle commonly in use, the turbine may be driven from low-pressure steam, or alternatively take high-pressure steam and exhaust to the low-pressure system. In the latter case, back-pressure machines offer the advantage of simple, robust driving units with a minimum of auxiliaries requiring control or maintenance. Also, the steam flow through the turbine is increased, permitting an improved blading design and higher efficiency.

Turning once again to reliability, the steam turbine does not possess the inherent simplicity of the squirrel-cage motor, and therefore its reliability will depend to a great extent upon design. However, the problem should be seen in correct perspective, and not confused with the difficulties arising on large modern machinery operating at elevated steam conditions. By using to advantage the modest power, temperatures and pressure, a robust mechanical design is possible, and the record of such machines in industrial applications is in many cases extremely good. The absence of electrical equipment must inevitably contribute to a reduction in sudden faults.

NEXT MONTH

The eighth article in the series will be ' Supply and regulation of boiler feed water ' by **J. W. W. Shaw,** *of the U.K. Atomic Energy Authority*

FLOW CONTROL

Variable-speed drives have been discussed in some detail. An alternative method of mass-flow control is by means of dampers located in the flow paths of the gas circuits. Such a system is proposed for the Trawsfynydd station. A by-passing duct is provided

STATION	NET OUTPUT PER REACTOR MW	NO. OF GAS CIRCUITS	GAS PRESSURE lbf/in² abs.	TYPE OF BLOWER	PRESSURE RISE lbf/in²	MASS FLOW lb/sec	DESIGN SPEED rev/min	MAXIMUM SPEED rev/min	DESIGN POWER INPUT bhp	MAXIMUM POWER INPUT bhp	BLOWER DRIVING UNIT	SPEED CONTROL
CALDER HALL and CHAPELCROSS	40	4	115	Centrifugal	5·53	500	854	940	1495	2200	D.C. motor	Ward Leonard (motor generator sets)
BRADWELL	150	6	147	Axial	7·6	877	3000	3300	3300	4400	Squirrel-cage induction motor	Variable frequency supply from auxiliary turbo-alternators
BERKELEY	137·5	8	140	Axial	7·25	805	2715	2903	3020	3800	Squirrel-cage induction motor	Fluid coupling
HUNTERSTON	150	8	165	Centrifugal	7·6	750	1040	1100	2255		D.C. motor	Voltage control from mercury arc rectifiers + phase shifters
HINKLEY POINT	250	6	200	Axial	8·63	1750	—	3000	5500	7000	Squirrel-cage induction motor	Variable frequency supply from auxiliary turbo-alternators
LATINA (ITALY)	200	6	196	Axial	10·1	1187	2250	2363	4115	4760	Squirrel-cage induction motor	Variable frequency supply from auxiliary turbo-alternators
TRAWSFYNYDD	250	6	255	Axial	—	1500	2950	2950	6200	—	Squirrel-cage induction motor	Constant speed
TOKAI-MURA (JAPAN)	150	4	224	Centrifugal	—	1500	—	—	7400	—	Steam turbine	Turbine governor
DUNGENESS	250	4	283	Axial	—	2650	2130	2240	9600	11,000	Back-pressure steam turbine	Turbine governor

around the blower, permitting the flow to the reactor to be adjusted by means of butterfly valves located in the main duct and in the by-pass duct.

The blower is driven at constant speed by a squirrel-cage motor supplied from a normal 50-c/s supply. At this speed the blower must deliver the maximum mass-flow required by the reactor under any conditions. When a lower mass-flow is desired, the surplus flow is diverted through the by-pass duct back to the blower inlet. This procedure does not affect to any extent the power absorbed by the motor, the variation depending upon the slope of the characteristic and the change of blower efficiency. If a margin of mass flow at design output is required then the surplus must be by-passed continually during normal operation.

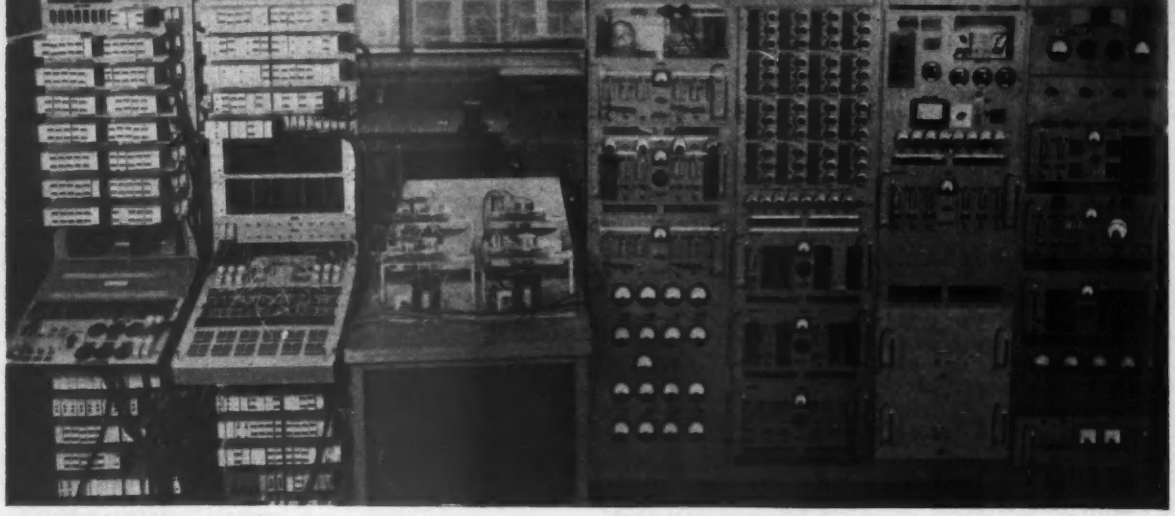
This form of mass-flow control suffers from the same disadvantages which exist on the fluid-coupling drive, in that efficiency both at the design point and at part load is reduced below that of a straightforward motor drive. Other features similar to the fluid-coupling drive are: first, the restrictions upon choice of blower speed; second, the interconnexion with—and therefore reliance upon—a larger electrical network.

The reliability of the drive is unquestionably high, the onus for trouble-free operation having been placed upon the valves in the gas circuit. If special valves are provided for gas control, additional to the isolating valves, then they can be designed without need for tight-sealing and with liberal clearances to ensure freedom from binding. The valves are also operating in the low-temperature region of the gas circuits, and maintenance should be less on this account. The control problems centre around combining the operation of all the gas valves so that synchronism and flow balancing is achieved over the whole range.

The cost of a constant-speed drive of this type, with flow control, is similar to that of the fluid-coupling drive, the method being less expensive than the turbo-electric but more than the steam turbine drive.

From the above it will be appreciated that the choice of blower drive for a particular project is difficult indeed. No one solution will apply in all cases, and the type of drive finally selected will depend upon such features as the type of blower, the maximum power required, the number of gas circuits on the reactor, the type of steam cycle, the anticipated load factor of the station, and finally a cost comparison taking into account all the variables. Only one trend is clear; with the larger powers required on high-output reactors, the choice is between the squirrel-cage induction motor and the steam turbine. Even then, there remain an appreciable number of different methods of using either of these two prime movers. Steam-turbine drive has the lowest initial cost, and, other characteristics being equal, it would therefore be selected.

Comparing the drives outlined in the accompanying table, it will be interesting to collate, after the passage of a few years, the relevant operating experience on each. Only then will assessments of merit be based upon some factual information rather than judgement.



PART 1

Versatile analogue computer for g.w. studies

by **MICHAEL G. HARTLEY** M.Sc.Tech.
Manchester College of Science and Technology

IN THE DEVELOPMENT OF GUIDED WEAPONS THE ANALOGUE simulator has proved an important aid. With such a machine the performance of a weapon may be investigated in some detail without expensive firings. In this connexion a demand arose for a versatile analogue machine which could simulate in a comparatively simple way a variety of missile and target courses in different guided-weapon systems. Such a machine has been constructed. It incorporates sufficient analogue computing equipment for a simplified two-dimensional simulation of missile and target aerodynamics and kinematics. If desired, the behaviour of the associated radar trackers may be simulated by the use of positional servo-mechanisms with suitable shaping networks. Range is provided by the instantaneous position of rate servo-mechanisms. Provision is made for the inclusion of noise-generation equipment to simulate tracker noise. Target manoeuvre may be simulated with function generators.

A two-dimensional simulation, covering a variety of situations, deals with the aerodynamics and kinematics of missile and target in a guided-weapon system. The machine has been operated for some time without serious fault, and the operational amplifiers function well. Valuable data about missile performances have been obtained.

The block diagram (see Fig. 1) shows the extent of the equipment. Target range and bearing information may be transfered from the simulated tracker to a digital computer. The analogue-to-digital converters consist of disks, coded in cyclic progressive code, attached to the output shafts of the servo-mechanisms. A row of small lamps illuminates the tracks of the disks. Reading photo-transistors are mounted on the side of the disks opposite to the lamps.

Data as to missile range and bearing may be applied in the same way to the digital machine. The digital machine is able to calculate a suitable course for the missile. In this simple two-dimensional case the instruction to the missile would take the form of a lateral acceleration demand. The analogue machine operates upon the acceleration demand through the simulated missile aerodynamics and kinematics to provide the resultant lateral displacement and hence missile range and bearing at the missile pick-offs. The digital machine is sufficiently fast to modify continuously its output acceleration demand in the light of further input data representing missile and target positions.

As an alternative to the above simulation, a completely analogue simulation is possible.

The remainder of this article is devoted in some detail

to the various sections of the analogue machine and servo-systems, in which several novel design features are included.

GENERAL DESCRIPTION

An overall front view of the simulator is shown opposite. The analogue section comprises four standard racks containing the operational amplifiers, main control panel, stabilized power supplies, gain adjustment panel and Wheatstone bridge, and equipment associated with the servo-systems. The interconnexion panel for the inputs and outputs to the operational amplifiers is at the rear. The racks are so arranged that further additions can be made with ease. The servo-systems are on the central bench. A pen recorder on the bench enables one to monitor the system at any point. The digital machine is at the left.

Computing elements

The principal computing element is the chopper-type, drift-corrected, d.c. amplifier which may be connected as either an amplifier, an integrator or as an active shaping network. When used as an amplifier its gain is set up using the gain adjustment procedure described later (under *Computing amplifiers with input and feedback resistances*). Accurate measurement of the input and feedback resistances is not required. Sixteen of the operational amplifiers may be used in this way. For the remainder, used as integrators, or for more complex transfer functions, accurate measurement is necessary. This applies also to the amplifiers associated with the servo-systems.

The operational amplifier is described in the next section. It is contained in a compact light-alloy standard sub-chassis with a front panel 6in high and 2¼in wide. It plugs into a larger chassis permanently fixed to the racks of the analogue machine. Each large chassis has space for six sub-chassis. It holds two heater transformers, and a 250-0-250 μA meter and seven-way switch are mounted at the front. The meter and switch enable one to monitor the outputs of the amplifiers at will. A push-button above the meter having been depressed, the sensitivity is increased so that full-scale deflexion corresponds to ±15 mV at the output of the amplifier under test. The value of the drift voltage referred to the input is this value divided by the amplifier's closed-loop gain.

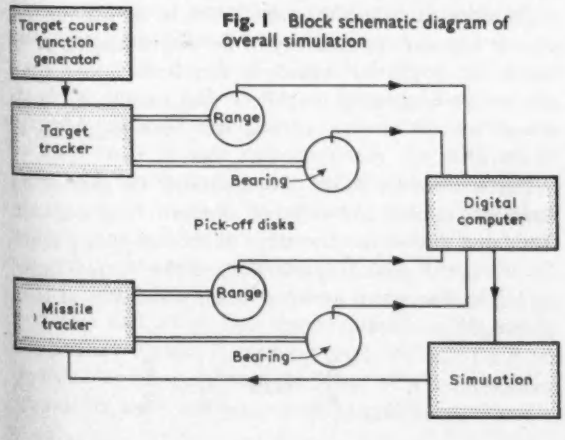


Fig. 1 Block schematic diagram of overall simulation

Heat dissipation ducts (*1*) are used above each six-unit chassis. By the use of this simple device the operating temperature is kept within reasonable limits.

As is usual with analogue computing machines, control is achieved by a relay system. In the zero set (z.s.) condition, relays are used to earth the input to each amplifier while the ' zero set ' potentiometer of each amplifier is adjusted for zero output from the amplifier. These relays are released for the other operating states, ' initial conditions ' (i.c.), and ' run '.

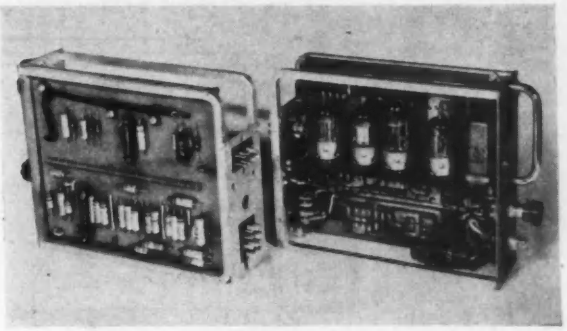


Fig. 2 Opposite sides of two amplifiers

In the ' initial conditions ' state, provision is made for insertion of initial voltages at the computing units used as integrator and active shaping networks. In the ' run ' condition all the elements are connected and computation is performed.

D.C. amplifier

The amplifier was designed a few years ago and was based on an R.A.E. circuit. It is constructed on two printed-circuit panels. The horizontal panel on which the valves and chopper relay are mounted is slotted into and soldered to the vertical component panel. The general construction is shown in Fig. 2.

The main amplifier uses five valves and has a triode output stage. The other half of V3 is used to establish a negative reference for the output triode. The circuit diagrams are shown in Fig. 3.

A double-triode amplifier with a Siemens relay type-130 is used in the drift correction channel. This relay is non-polarized, giving a 100-c/s chopping frequency from a 50-c/s supply. The gain of this channel at d.c. is 120. The neon connected to the output provides a true overload device and indicates any departure from linearity or fault where the input grid is no longer a virtual earth. The overall gain of the amplifier at d.c. is 3×10^6, and with a defined gain of 100 the band-width is 4 kc/s. Over periods of a few days the drift, referred to the input, is less than 1 mV. The output swing is ±60 V into a 10-kΩ load.

Although the performance of the amplifier is inferior

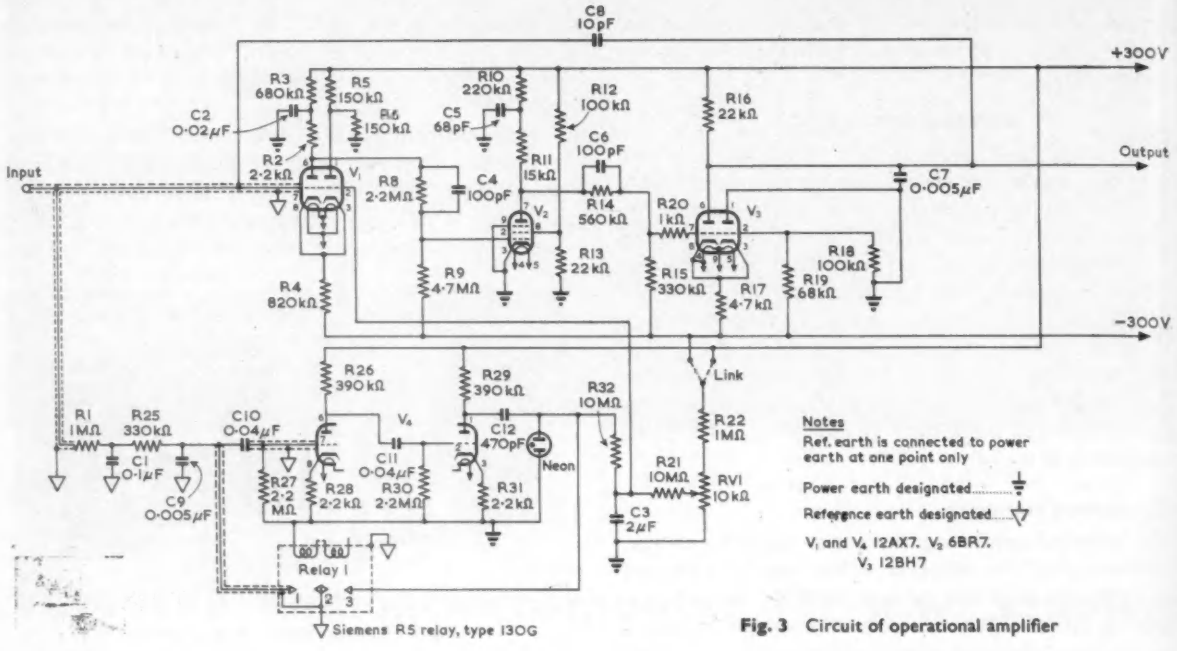


Fig. 3 Circuit of operational amplifier

to that of many now available commercially, it is adequate for the computation in which it is used. Twenty-five of these amplifiers have been in continuous use for two years and have given remarkably little trouble.

Computing amplifiers with input and feedback resistances

When used with resistances as input and feedback components, the amplifier may perform the arithmetic processes of addition, scale changing and sign reversal. A maximum of three inputs may be applied to amplifiers used in this manner in the machine. A single amplifier may be used to perform more than one of the functions

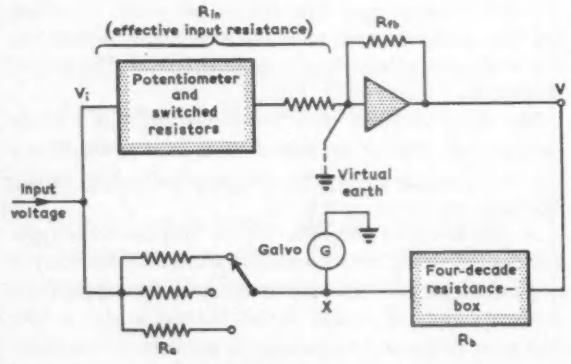


Fig. 4 How the gain is adjusted

simultaneously. In the above applications the ratio of feedback to input resistance is the principal factor which determines the accuracy of the computation.

For the case of simple scale-changing, for example, with an input voltage v_i and output voltage v_0, the following relation holds (*2*).

$$\frac{v_0}{v_i} = \frac{-R_{fb}}{R_{in} + (1/M)(R_{in} + R_{fb})} \qquad (1)$$

where R_{in} = computing resistance at the amplifier input.
R_{fb} = feedback resistance.
$-M$ = open-loop gain of the operational amplifier.

Since, as was seen in the previous section, the gain M in this case is 3×10^6, it is permissible to take

$$v_0/v_i = -R_{fb}/R_{in} \qquad (2)$$

Normally resistors are measured as carefully as possible with a Wheatstone bridge. This method is lengthy. An accuracy of rather better than 1% is normally achieved. After measurement the resistances are usually soldered into the circuit. Their ratio will change as a result of unequal heating during soldering, subjection to different ambient temperatures, and unequal aging with time. It is not normally easy to check and adjust the resistance values later.

In order to reduce the time taken in setting up, and also to improve the accuracy of the determination of the ratio, an improved technique has been adopted for the sixteen computing amplifiers used exclusively in the above role. A similar method has been suggested by Wass (*3*).

Fig. 4 shows the mode of operation of the gain-setting technique applied to one input of a particular amplifier. The input grid of the first stage of the computing amplifier is at earth potential, according to the 'virtual earth' principle. Balance is achieved when point X is at earth potential, i.e. when,

$$\frac{|v_i|}{|v_0|} = \frac{R_{in}}{R_{fb}} \quad \text{and} \quad \frac{|v_i|}{|v_0|} = \frac{R_a}{R_b} \qquad (3)$$

Hence $$R_{in}/R_{fb} = R_a/R_b$$

Fig. 5 shows a simplified circuit diagram of the gain-adjustment technique. The arms of the bridge are connected *via* jack-plugs to the appropriate input and to the output of the amplifier under consideration. The insertion of the jack-plug at the amplifier input automatically disconnects the amplifier from the output of the previous amplifier. The other two inputs to the amplifier are earthed during gain setting.

The input resistor selector switch is set to give approximately the desired ratio for v_0/v_i. The ratio R_b/R_a is set up on the bridge so that,

$$\frac{R_b}{R_a} = \frac{|v_0|}{|v_i|} \qquad (5)$$

Balance is achieved by adjustment of the 100-kΩ potentiometer at the input to the amplifier. The values of the input resistances are chosen so that the ratio $|v_0|/|v_i|$ is continuously variable from about 0·25 to 7·5. Using this method the gain of the computing element may be quickly changed with ease. The ratio is set up with the resistors already in place. Differences in their ambient temperature are unimportant. The ratio may be checked occasionally without disturbing the problem on the machine.

Technique to check gain-setting.

Tests were made using two amplifiers set to a nominal gain of unity. The circuit is shown in Fig. 6. One input to the second amplifier is the input voltage common to both the amplifiers. The other is a voltage, reversed in sign, and of a magnitude differing from the input voltage to the extent by which the gain of the first amplifier departs from unity. Owing to the sign reversal, the second amplifier subtracts one from the other. As shown in the appendix, the sum of a reading before and after reversal of inputs to the second amplifier is a measure of the error in the gain of the amplifier under test. The use of the reversing switch removes error owing to the inequality of gain in the two channels of amplifier two. Experiment showed that the error in the gain of the test amplifier was negligible.

Computing amplifiers as integrators and for active shaping networks

Eight computing elements are connected to perform the above functions. The relays which switch in the circuits associated with the three conditions of operation are mounted directly behind the computing amplifiers. At z.s. the amplifier is earthed. At i.c. the unit is arranged as an amplifier with gain determined by the ratio of i.c. input and feedback resistors. For the ' run ' condition the i.c. input voltage is removed and the feedback resistor disconnected to leave the feedback condenser charged to the appropriate initial voltage.

The resistances and condensers must be individually measured and wired into the circuit. The bridge mentioned above (under *Computing amplifiers with input and feedback resistances*) may be used in a conventional manner for the measurement of the resistances.

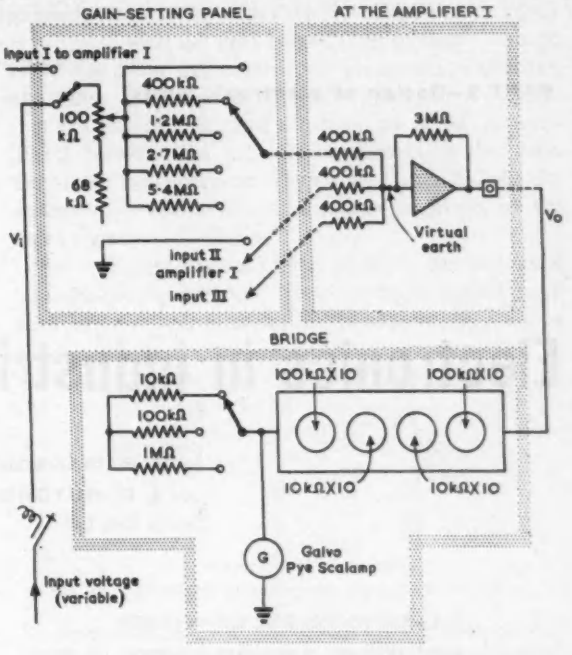


Fig. 5 Circuit for gain adjustment

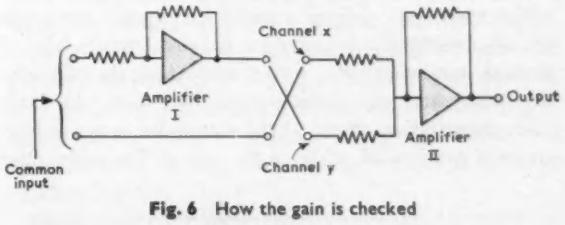


Fig. 6 How the gain is checked

Coefficient potentiometers

Sixteen coefficient potentiometers are provided in the machine. Ten-turn helical potentiometers are used in conjunction with a 100-V reference line. In operation, the potentiometer dial is set to the nominal value desired. A special ' voltage-measuring unit ' is used for the final potentiometer setting. In this way voltages may be set to about 0·1% of the desired value. The measurement may be taken with the slider of the potentiometer connected to its appropriate load. Leading errors are thus avoided.

Patch panel

The inputs and outputs of the various computing elements, amplifiers, potentiometers, external connexions etc. are brought out to a patch panel at the rear of the machine to facilitate rapid setting-up. Sockets are easily identified by means of a colour code.

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2. Wass, C. A. A.: *An introduction to electronic analogue computers* (Pergamon Press Ltd, London 1955) p. 95.
3. *Ibid.* p. 115.

To be continued

PART 2—Design of electronic units

Last month's instalment was about system design. In Part 2 the authors get down to the design features of electronic components

Electronics in industrial process control

by **G. B. MARSON** B.Sc., A.Inst.P.
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George Kent Ltd

A.C.-RATIO-TO-D.C. CONVERTER

Although most primary measuring elements or transducers provide, or can be made to provide, a direct voltage or current output, there are a few such devices which essentially deliver a small a.c. signal, and these are of considerable importance in extending the field of possible measurements. Two examples are the magnetic flowmeter and the liquid-conductivity cell. In both cases polarization effects at the electrodes cause serious errors if d.c. is used, while in the case of flowmeters, the high power required to generate the magnetic field is an added reason for supplying the device from the a.c. mains. For obvious reasons it is usually uneconomic to stabilize the a.c. supply, and consequently the output rises and falls with changes in mains voltage.

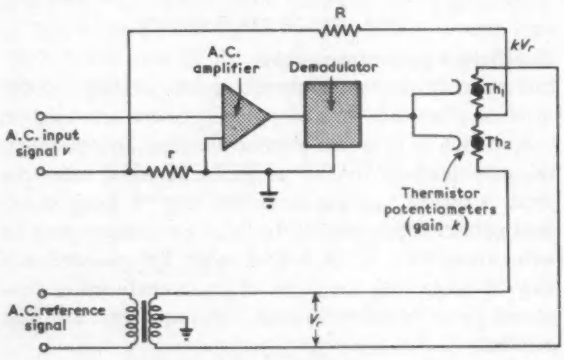


Fig. 9 Solid-state servo-system

A modular control system based on a d.c. transmission signal must therefore contain one or more units which will convert the ratio of two a.c. signals into a direct current, with an accuracy of a fraction of 1%. This can be done by what is in effect a 'solid-state servo-system' (*5*), using indirectly heated thermistors to replace the conventional slide-wire, and frequency-sharing methods to determine the position of the slide-wire 'contact'.

SOLID-STATE SERVO-SYSTEM

Consider Fig. 9. The only difference between this and the conventional a.c. servo-system is that the servo-motor and slide-wire have been replaced by a demodulator and two indirectly heated thermistors. These are arranged so that the presence of an a.c. error signal lowers the resistance of one of the thermistor beads and raises that of the other, so moving their common point towards one end of the total resistance. The total resistance remains very approximately constant, though this is of no fundamental importance, and the action is phase-sensitive, reversing when the phase of the error signal reverses. Thermal lag in the beads is sufficient to smooth the demodulated drive signal. The system drives itself towards a condition of balance in the usual way until, if the amplifier has a high gain

$$v = k\,V_r\,\frac{r}{R+r}$$

i.e.

$$k = \frac{R+r}{r}\cdot\frac{v}{V_r}$$

Thus the gain k of the thermistor potentiometer, defined as the ratio of its output to the voltage applied across it, is automatically adjusted in proportion to v/V_r, the ratio of two a.c. signals.

FREQUENCY SHARING

In the conventional servo-system, the slide-wire is linear, and k is displayed by the position of the contact which is usually geared to a pen and pointer. In the solid-state system no such display is available, but the thermistor potentiometer can be used to provide a d.c. out-

put which is proportional to k if an additional d.c. reference voltage is impressed across it.

One way in which this can be done is shown in Fig. 10. The a.c. reference is provided by two separate windings on a transformer, and a d.c. reference is connected between the windings with its centre point earthed. Provided that both the windings and the d.c. reference have negligible impedances, the whole of V_r and V_z is impressed across the thermistor potentiometer, and the latter's output is therefore $k(V_r + V_z)$. It is a fairly simple matter to separate the a.c. and d.c. components, so that kV_r is fed back to balance the a.c. input signal, and kV_z is amplified to provide the required direct output current. We then have

$$\text{output} = kV_z = \frac{R}{r}\,\frac{v}{V_r}\,V_z$$

i.e. the d.c. output is proportional to the ratio of two a.c. inputs multiplied by the direct reference voltage. It does not matter in practice if the output of the thermistor potentiometer is quite heavily loaded, provided that the loading is the same for both d.c. and a.c.

Converter for magnetic flowmeters

Fig. 11 is a block diagram of a complete a.c.-ratio-to-d.c. converter based on the foregoing principles and designed specifically for use with electromagnetic flowmeters. It is fully transistorized and takes the same form as the d.c. amplifiers described in the next section, mounting in the same 3 in × 6 in × 18 in light-alloy chassis and using the same power-supply sub-units and a chopper-type d.c. amplifier of similar but simpler design.

A well-shielded input transformer, with a high inductance and a low core-loss, isolates the flowmeter electrodes from the amplifier earth, and range-changing facilities are built in. Since the flowmeter output signal is in phase with the field current, the reference voltage is derived from this current *via* a current transformer and shunt. Both signals lag behind the mains by nearly (but not exactly) 90°, and a further lag of 90° is introduced between the a.c. pre-amplifier and the main thermistor potentiometer so that the latter (whose demodulator operates at mains phase) is driven by the input signal.

An important feature of the design is the automatic 'quadrature suppression' provided by a second feedback loop. A second thermistor potentiometer is driven

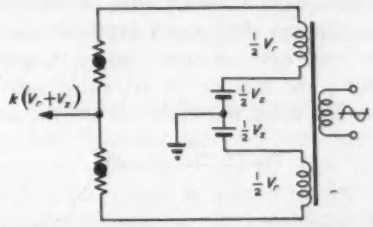
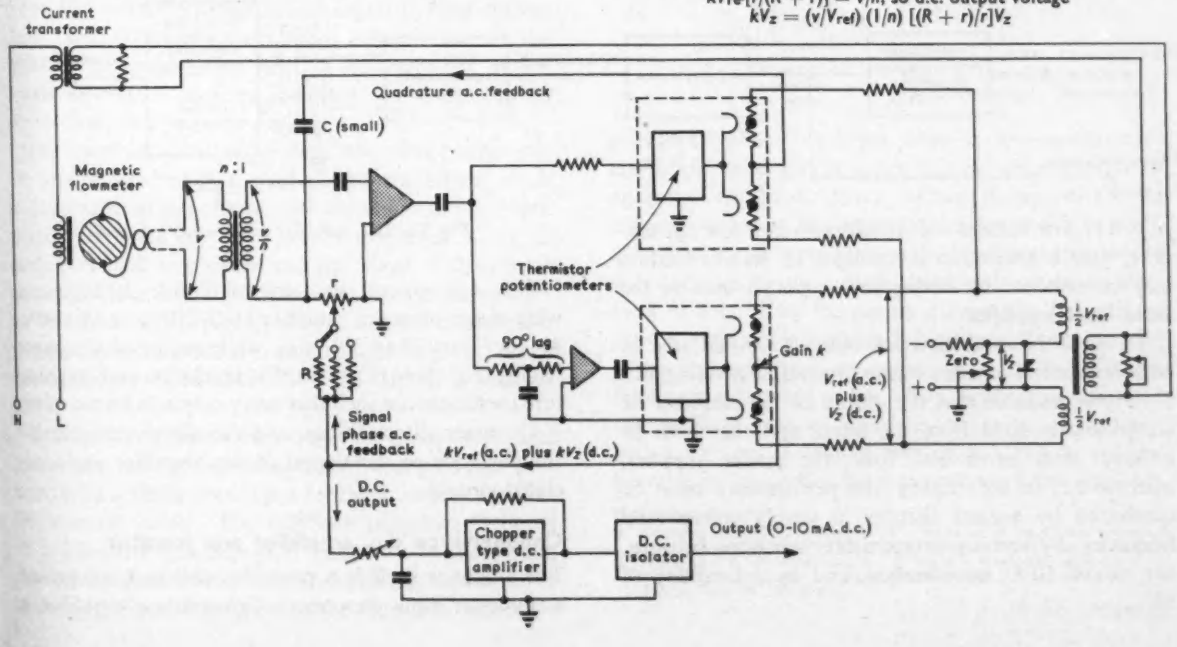


Fig. 10 Thermistor potentiometer sharing a.c. and d.c.

by signals which are at 90° to those in the main measuring loop, and feeds back a suppression signal which is derived from the reference and is at precisely 90° to it. This arrangement removes any residual signal, such as would be caused by a phase error in the input signal, without introducing any additional signal at reference phase. The result is to reduce to negligible proportions any errors in measurement which the residual signal might cause (owing to demodulator phase errors etc.) and to eliminate all possibility of saturation by large residual signals.

In its final form the converter provides an output of

Fig. 11 A.C.-ratio-to-d.c. converter. At balance, k is given by $kV_{ref}[r/(R+r)] = v/n$, so d.c. output voltage $kV_z = (v/V_{ref})\,(1/n)\,[(R+r)/r]V_z$

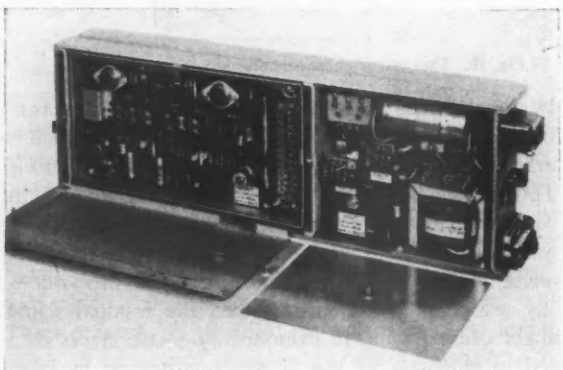


0 to 10mA d.c. for a.c. inputs to 0–½mV upwards. The input impedance in the steady state is about 10MΩ, and the overall linearity is in the region of ±0·2%. Operation is virtually unaffected by normal changes in supply voltage or frequency, and by changes in ambient temperature between 0 and 50°C. The full-scale response time is about 2s.

LOW-DRIFT D.C. AMPLIFIER

Signal converters with direct voltage inputs and control units, as described last month, are both based on the use of low-drift d.c. amplifiers. The requirements for these two applications are not identical, since a thermocouple converter must have a voltage drift of less than a few microvolts, whereas the control amplifier, as explained previously, must have an input current of the order of 10^{-9}A, with some latitude in allowable voltage drift. However, when using transistor circuits the attainment

Fig. 12 D.C. amplifier



of a very low voltage-drift results also in a low current-drift, and considerable advantages in standardization may be obtained by basing both types of unit on the same basic amplifier.

To avoid the troubles which otherwise would arise in complex control schemes owing to multiple earthing etc., it is very desirable that the output of the amplifier be completely isolated from the input, and that both be isolated from earth and from the power supplies, whether a.c. or d.c. Lastly, the performance must be unaffected by normal changes in supply voltage and frequency, by ambient temperature variations between, say, 0 and 50°C, by vibration, and by a humidity of 95%.

Construction

The d.c. amplifier shown in Fig. 12 is itself constructed on a modular basis, and is really one of a family of designs, all of which use the same power supply sub-units, the same output transistor and the same d.c. isolator. The family includes several designs of electronic controller, the a.c.-ratio-to-d.c. converter, and an amplifier with very high input-impedance for pH application.

The power supply sub-units, as well as the output transistor and isolator, are mounted in the rear half of a chassis of standard design, and the whole family of designs is constructed by adding the appropriate circuit cards at the front. Thus the unit shown in Fig. 12 contains a transistor chopper-type d.c. amplifier (*6*) suitable for use with thermocouples, resistance thermometers etc., together with a removable range-card which carries all the components which may have to be changed to suit the application. Certain types of proportional and three-term controllers can also be made merely by changing the range card.

Power supplies

The power supply system is shown in Fig. 13. A transformer and rectifier unit provides d.c. from the mains, and this is fed to a transistor-and-Zener-diode regulator which delivers 17V d.c. ± 1% to a relaxation oscillator. The oscillator provides a number of 200-c/s square-wave outputs. Some of these are rectified and smoothed in a 'distribution unit' and made available as floating h.t. supplies for the amplifier. Others are left in a.c. form to drive the transistor chopper and demodulator, and to supply the output transistor and the d.c. isolator.

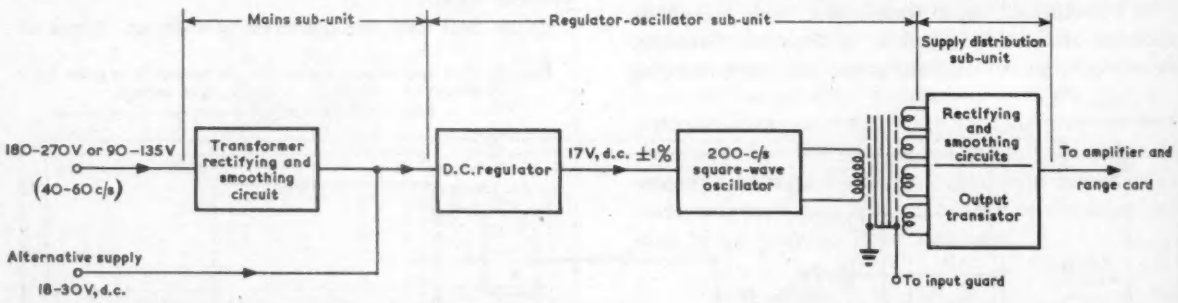


Fig. 13 D.C. amplifier power-supply system

This arrangement has several merits. It accepts a wide range of mains supplies (180–270V, or 90–135V, 40–60c/s) or 18 to 30V d.c., while requiring a selector having only three positions. The regulation and temperature coefficient are such that every output is stable within ±1% under all conditions, and this allows considerable simplification in the design of the amplifier and associated circuits

Chopper-type d.c. amplifier and isolator

The amplifier itself is a printed-circuit unit comprising a transistor input chopper, a high-gain a.c. amplifier, a

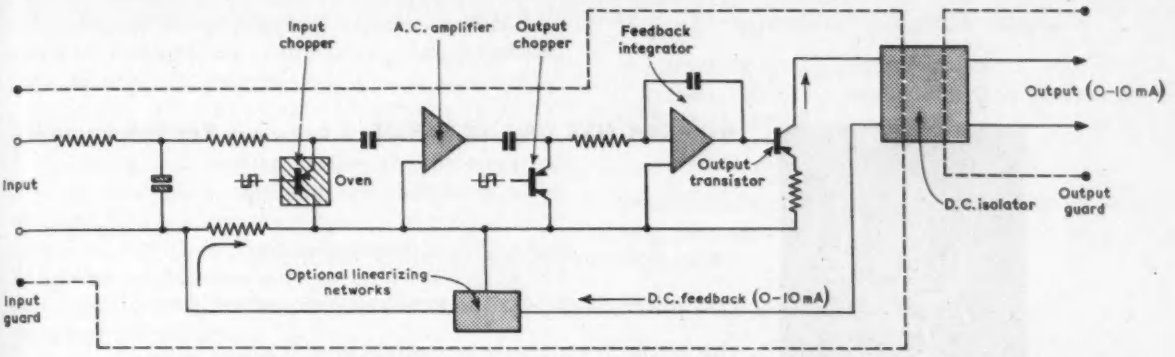


Fig. 14 Operation of d.c. amplifier

transistor demodulator, and a feedback integrator which smooths the demodulated output of the a.c. amplifier. The integrator provides a final d.c. output of 0 to 5V at 1mA maximum.

The amplifier is shown in block form in Fig. 14, together with the rest of the system for millivolt measurement. The other items are an input filter, which is carried on the range card together with the feedback components, an output transistor which is mounted in the distribution unit and converts the amplifier output into a signal of 0–10mA d.c., and the d.c. isolator. The latter is a self-contained sub-unit based on a low-loss current transformer, having a gain of unity $\pm 0{\cdot}15\%$ at 10mA d.c. and delivering 0–10mA d.c. into any load up to 2kΩ.

In cases where an isolated output is not required the isolator can readily be by-passed to increase the overall accuracy of the system.

The drift of the system is almost entirely determined by the input chopper. This is a silicon transistor, and in cases where the voltage drift must not exceed a few microvolts the device is mounted in a miniature oven controlled within ± 2degC at about 60°C. The current drift depends much less on the temperature of the transistor chopper, and when a voltage drift in the region of 100μV can be tolerated, the oven and its control amplifier may be omitted.

The amplifier card, range card and distribution unit are totally enclosed by a conducting metal screen which is isolated from the chassis and connected to an 'input guard' terminal. In cases where the input is not at earth potential, this screen can be driven at the source potential, *via* a third input wire connected to the source, so that there is no pick-up in the amplifier. By these means, common-mode d.c. or a.c. input signals can be attenuated by more than 10^6 times, up to a limit of 300V.

The a.c. amplifier comprises two groups of three transistors, each group being directly coupled and provided with a single overall d.c. feedback loop to stabilize the working points. The feedback integrator is based on a low-drift *npn–pnp* pair. Response of the system depends on a number of factors, including the degree of smoothing, but is typically better than 0·2s full scale when the feedback is adjusted to provide overall gain stability of 0·05%. The response to small input signals is in the region of 10c/s.

THERMOCOUPLE CONVERTER

The input and feedback circuitry for thermocouple measurement is shown in Fig. 15. The Wheatstone bridge in the input circuit is used to nullify the effect of temperature changes on the cold junction of the thermocouple. This junction is located at terminals in the converter's outer case, close to the temperature-sensitive resistor R. The increase of this resistance with temperature causes an increase in the out-of-balance bridge voltage, which compensates for the change in e.m.f. of the cold junction. The bridge is supplied by a

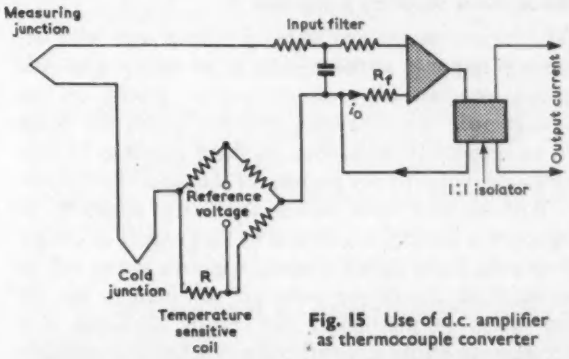


Fig. 15 Use of d.c. amplifier as thermocouple converter

reference voltage obtained from a low-temperature-coefficient Zener diode, which is itself supplied with an accurate, stabilized, direct current derived from the 200-c/s oscillator. The compensated thermocouple e.m.f. is applied *via* an input filter to the amplifier input, where it is balanced by the voltage developed across the feedback resistor R_f by the output current i_0. The gain of the d.c. amplifier is sufficiently high for full output swing to be obtained from an output less than 0·5% of the minimum measuring range. When larger spans are used, the feedback voltage must be increased accordingly, and to prevent instability the forward gain is reduced by attenuation within the a.c. portion of the amplifier.

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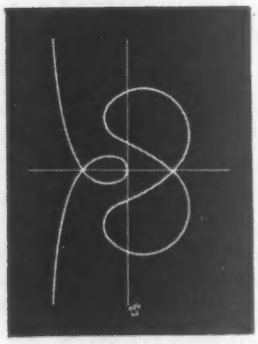


NUMBER FIVE OF THE SERIES PART A

How the root-locus stability criterion compares with stability standards based on the usual frequency response methods

Pole-zero approach to system analysis

by **P. F. BLACKMAN**

Imperial College of Science and Technology

Root locus stability criterion

The various design and stability criteria used with frequency response methods such as *M*-circles, gain and phase margins, represent restrictions placed on the system open-loop frequency response which will result in an acceptable closed-loop transient response by constraining indirectly the position of the closed-loop poles.

With the root locus method the fact of instability as opposed to stability is indicated by the presence of closed-loop poles in the right half plane, while the system will be stable if all closed-loop poles are restricted to the left half plane. In addition to this test by inspection it is necessary to obtain some criterion to define an acceptable transient response, since poles very close to the imaginary axis correspond to natural-mode components which decay very slowly.

For a system in which the closed-loop transfer is dominated by a single conjugate pair of poles, corresponding to a transfer of the general form

$$T(p) = 1/[(p/\omega_n)^2 + 2\zeta(p/\omega_n) + 1]$$

the response to a step input, which is the normal step response for any system, whether closed-loop or not, governed by a second-order differential equation is shown in Fig. 1a, with damping ζ as a parameter together with the corresponding pole locations.

A damping value of $\zeta = 0{\cdot}4$ is a convenient choice, corresponding to a maximum overshoot of about 25%, and the usual *M* criterion of $M_{max} = 1{\cdot}3$ corresponds to $\zeta = 0{\cdot}42$ (*1*). Thus a criterion of acceptable transient response for systems dominated by a single pair of poles is that the radial angle between the poles and the negative real axis should be

$$\theta = \cos^{-1}\zeta \simeq 66° \text{ (for } \zeta = 0{\cdot}4)$$

This criterion essentially specifies a ratio between real and imaginary components of the pole, since motion along a radial line from the origin, corresponding to a constant ratio α/ω, merely alters the time-scale of the response but not the actual form, as shown in Fig. 1b.

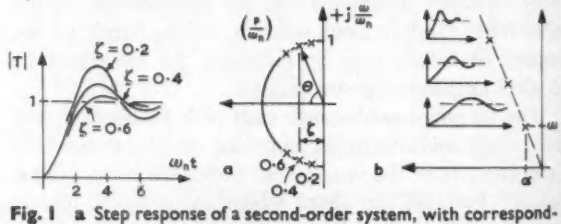


Fig. 1 **a** Step response of a second-order system, with corresponding pole locations
b Change in time scale of response on radial motion of poles

The criterion just developed is adequate for the common situation of a system which is dominated by a single pair of poles, or when additional poles are well removed to the left corresponding with transient components decaying rapidly compared with those for the forward poles. For systems which have several poles contributing significantly to the overall transient response, the actual form of the response depends on the detail of the *p*-plane pattern.

In order to obtain a correlation between the root locus stability criterion (which deals directly in terms of system

poles) and the normal frequency response methods, it is useful to investigate the interpretation of these methods from the root locus point of view.

Relation between p-plane and T-plane

If $T(p)$ is a general transfer function, then for any value of p, say p_r, a value in magnitude and phase form can be obtained for $T(p_r)$, and if a T-plane is considered to be associated with the p-plane the values p_r and $T(p_r)$ can be plotted in their respective planes as in Fig. 2a, the actual relation between the two points depending on the particular form of $T(p)$.

If p_r is moved through a succession of values

$$p_r, p_{(r+1)}, p_{(r+2)}, \ldots$$

along a path in the p-plane, the corresponding values

$$T(p_r), T(p_{r+1}), T(p_{r+2}), \ldots$$

can be plotted in the T-plane, and if the points lie on a smooth line in the p-plane a smooth line will result in the T-plane, as in Fig. 2b. If a second set of points

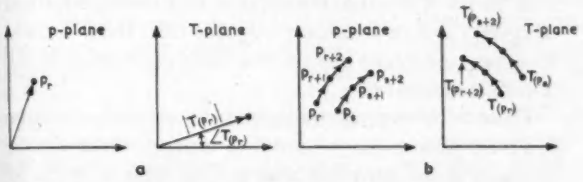


Fig. 2 a Relation between p_r and $T(p_r)$ in p- and T-planes
b Relation between a series of points in p- and T-planes

$p_s, p_{(s+1)}, p_{(s+2)}, \ldots$ is taken in the p-plane adjacent to the previous values, a further series of values $T(p_s)$, $T(p_{s+1})$, $T(p_{s+2})$, . . . will be obtained in the T-plane adjacent to the original set.

If the point in the p-plane moves round a path s_1 in the p-plane (Fig. 3), the tip of the T vector will traverse a path s_1' in the T-plane which will generally be of different

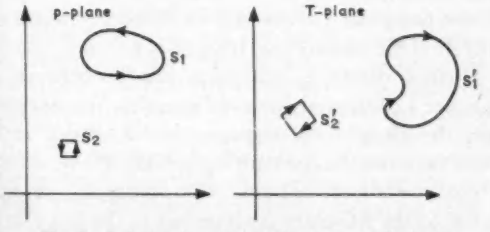


Fig. 3 Relation between paths in p- and T-planes

shape from s_1. If however the path in the p-plane becomes very small s_2, the exact shape of s_2 will be reproduced in the T-plane by s_2' except that the orientation and size may be different. The relation between the two planes is a *conformal transformation.*

Application to a system

In stability investigations, whatever actual method is being used, interest centres on values of p which satisfy the relation $KG(p) = -1$, since these values give the poles of the closed-loop transfer

$$\theta_o(p)/\theta_i(p) = KG(p)/[1 + KG(p)]$$

and hence the system's natural modes.

Initially, consider a system with three time constants in the forward path, having a transfer

$$KG(p) = K_1/(p\tau_1 + 1)(p\tau_2 + 1)(p\tau_3 + 1)$$

giving three poles on the negative real axis in the p-plane, with 180° lines crossing the imaginary axis at ω_1 as in Fig. 4a.

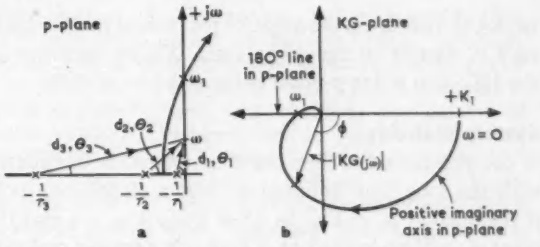


Fig. 4 Relation between p-plane plot and frequency-response plot in KG-plane

If values of $p \equiv j\omega$ along the imaginary axis are considered, corresponding $KG(j\omega)$ values or the normal open-loop frequency response are obtained, and may be plotted in magnitude and phase form in an associated KG-plane. For a general frequency value ω, the value $KG(j\omega)$ is obtained from the p-plane pattern as

$$|KG(j\omega)| = \frac{K_1}{\tau_1\tau_2\tau_3}\left(\frac{1}{d_1d_2d_3}\right),$$

$$\angle G(j\omega) = -(\theta_1 + \theta_2 + \theta_3) = -\phi$$

From inspection of the pattern in the p-plane the general form of the KG-plane path will be as in Fig. 4b with $\angle G(j\omega)$ changing from $0 \rightarrow -3\pi/2$ accompanied by a continuous decrease in magnitude. In particular since at $p = +j\omega_1$

$$\angle G(j\omega_1) = 180°$$

the corresponding point will lie on the negative real axis in the KG-plane. The general path obtained in the KG-plane will be the *transformation* of the imaginary axis in the p-plane, and if negative values of ω are considered a mirror image path will be obtained in the KG-plane.

If in the vicinity of ω_1 in the p-plane additional paths forming the normal σ,ω co-ordinate network in the plane are transformed into a network in the KG-plane, the general form will be as in Fig. 5.

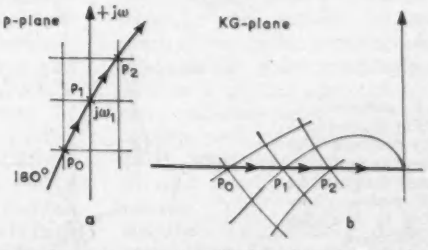


Fig. 5 Transformation into the KG-plane (b), of the region in the p-plane (a), where a 180° line cuts the positive imaginary axis

If K_1 is altered from an initial value this will not change the form of the network in the KG-plane, but merely increase or decrease the size of the net since $\angle G(p)$ is unaffected by variation of gain K_1.

Points along the 180° lines in the p-plane are those for which $\angle G(p) = 180°$, and hence lie along the negative real axis in the KG-plane, so that the succession of points in Fig. 5

$$p_0 = -a_0 + j\omega_0, \quad p_1 = 0 + j\omega_1, \quad p_2 = a_2 + j\omega_2$$

would be located on the negative real axis in the KG-plane with p_2 nearest to the origin since $|KG(p)|$ decreases as the 180° line in the p-plane is traversed to infinity.

System stability

If the present three-time-constant system is considered with the loop gain adjusted so that a closed-loop pole is obtained at p_0 in Fig. 5a, then $KG(p_0) = -1$ and the point p_0 will be located at -1 on the negative real axis

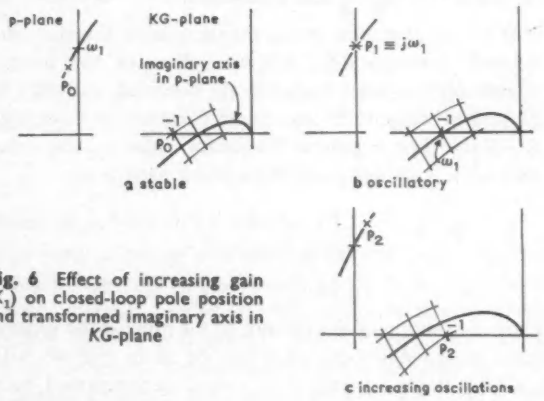


Fig. 6 Effect of increasing gain (K_1) on closed-loop pole position and transformed imaginary axis in KG-plane

in the KG-plane (as in Fig. 6a), and the transformation of the imaginary axis in the p-plane will pass below this point.

If the value of K is increased, the closed-loop pole could move to the imaginary axis at p_1, corresponding to an oscillatory system, and since the plot on the KG-plane will also increase in size, the point $p = j\omega_1$ on the transformed imaginary axis is now located at -1 in the KG-plane, as in Fig. 6b. Finally, if the value of gain is further increased the closed-loop pole moves into the right half plane, to (say) p_2, and this point will now lie at the -1 point in the KG-plane.

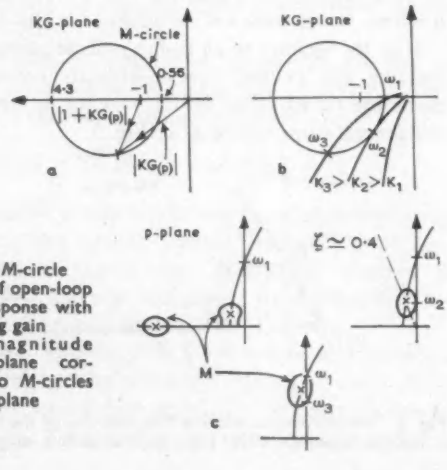


Fig. 7 a M-circle
b Variation of open-loop frequency response with changing gain
c Constant-magnitude lines in p-plane corresponding to M-circles in KG-plane

These results show that the position of the closed-loop poles relative to the imaginary axis, which forms the p-plane stability criterion, is in the KG-plane the relation between the transformed imaginary axis from the p-plane and the -1 point in the KG-plane. Since the transformed imaginary axis in the KG-plane is a plot of the open-loop frequency response the stability criterion in this plane is the normal Nyquist criterion depending on enclosure of the -1 point (*2*).

M-circles

In addition to a criterion for stability or instability, some measure of adequately damped transient response is required, which in the p-plane is obtained by positioning the closed-loop poles sufficiently far from the imaginary axis. In the KG-plane this requires that the transformed imaginary axis or frequency response clear the -1 point by some appropriate margin, this being determined by the use of M-circles (*3*).

These circles represent all possible combinations of the two magnitudes, $|KG(p)|$ and $|1 + KG(p)|$, which can be obtained in the KG-plane with a fixed ratio M given by

$$|KG(p)|/|1 + KG(p)| = M = |\theta_0/\theta_1(p)|$$

which gives the magnitude of the closed-loop transfer. The form of the circle for $M = 1{\cdot}3$ is shown in Fig. 7a. For increasing values of gain K_1, K_2, K_3, the plotted open-loop frequency response in the KG-plane might be related to the circle as in Fig. 7b, and K_2 represents the limiting gain for that frequency response which will give an acceptable transient response, since the locus touches the circle at ω_2.

If the complete α,ω net that could be developed outwards from the transformed imaginary axis is considered, the M-circle defines a continuous relation between α,ω and hence a continuous series of complex frequencies for which the closed-loop response is 1·3, which in the p-plane becomes the constant-magnitude line of value M for the *closed-loop* pattern. The frequency response criterion in the KG-plane corresponds to the fact that the constant-magnitude line of value M touches the imaginary axis in the p-plane. This situation ensures that the actual poles are sufficiently removed from the imaginary axis. The general form of the 1·3 constant-magnitude line for different closed-loop pole positions is indicated in Fig. 7c for the upper half plane only.

In addition to the conjugate closed-loop poles there is a third pole on the negative real axis. This pole is not evident from the frequency response criterion, and although it would not significantly affect the transient response of the system, the root locus method does draw attention to its presence.

To be continued

Semiconductor developments

New devices discussed at international symposium in France

by **S. HANDEL** A.M.I.E.E.

THE INTERNATIONAL SYMPOSIUM ON Semiconductor Devices which took place in the Unesco building in Paris from 20–25 February, brought together over 1000 of the world's leading workers in the semiconductor field. The French physicist, Louis de Broglie, who presided, sketched the broad theoretical background to the art, and about 150 papers were read.

Reliability

Many of the papers discussed the remarkable rate of improvement in design, performance, range and reliability of 'conventional' semiconductor devices. Thus, C. G. Thornton of Philco, U.S.A., described how the measurement and control of electrical properties at each step in the manufacture of germanium micro-alloy diffused transistors resulted in the production of low-cost, very high frequency switching transistors, with a failure rate of less than 0·1% per 1000 hours at 125°C—a value which may be extrapolated to a figure of better than 0·001% at 60°C. W. A. Adcock of Texas Instruments, R. Brewer of G.E.C. Research, and J. M. Groocock of Standard Telephones, read papers dealing with extensive reliability studies and with data accumulated from routine manufacturing tests which showed how the relation between reliability and temperature, humidity, and electrical stress can be established. G. H. Zierdt of General Electric, U.S.A., made the point that dramatic improvements in the results of storage tests meant that such tests no longer yield the maximum information, and they have now been replaced by comprehensive operating tests.

Improved s.c.r.s

Recent improvements in silicon controlled rectifiers were featured in several papers. J. Lecorguiller of Compagnie Française Thomson-Houston reviewed some of the advantages obtained with these devices over thyratrons, and other types of rectifier, in d.c.-to-a.c. inverters and d.c.-to-d.c. converters. The elimination of cathode-heating circuits allows a large amplification, and the much shorter rise and de-ionization times of the solid-state device leads to increased reliability. A. C. Stumpe of A.E.G., Frankfurt, described a practical inverter, with auxiliary circuits for turning off the silicon controlled rectifier, which delivered output powers up to 2 kW from a 100-V 250-c/s supply with better than 80% efficiency. A. E. Jackets of G.E.C., Wembley, gave details of a circuit employing Zener diodes, transistors, and silicon controlled rectifiers, which can break current from a supply in a few microseconds.

Improvements in design and performance have led to improved devices including: a germanium mesa transistor with f_{max} of 500 Mc/s and dissipated power of about 500 mW; a double-diffused silicon transistor with alpha cut-off of 20 Mc/s and a maximum current of 3 to 5 A; an alloy-diffused voltage-reference silicon diode with short-term stability ten times better than conventional types, and a temperature coefficient of less than 0·01% per degree C.

New devices

More than a dozen papers dealt with the theory, design, and fabrication of tunnel diodes. W. Cady of General Electric, U.S.A., described germanium and gallium-arsenide tunnel diodes, in current production, which operated in the kilo-megacycle range with switching times in the milli-microsecond range. Dr Amer and Dr Fulop of Standard Telecommunication Laboratories compared the results obtained from an experimental tunnel diode having three ohmic contacts, with a theoretical analysis, and pointed out that, while the tunnel diode already shows great promise in fast computer applications, its versatility would be enhanced by adding a third terminal. A research team from Siemens and Schuckert described a gallium-arsenide tunnel diode with peak currents of several amperes and peak-to-valley current ratios up to 50:1. G. B. Henry of R.C.A. Laboratories said that a clock rate of 1 kMc/s is now feasible.

A surprising number of papers dealt with new solid-state devices of various different geometries based on the field effect. Of these, the Tecnetron, a unipolar field effect device using centripetal striction, is already in production in France. The Tecnetron is a relatively high impedance device in contrast to the low impedance junction transistor. Unipolar devices have possible applications in the instrumentation and control of nuclear plant and satellites since they are much less affected by high-intensity radiation than bipolar devices.

Interesting new devices making their debut at the symposium included: experimental gallium-arsenide bipolar transistors, from Texas Instruments, with fast switching applications at temperatures as high as 350°C and with leakage currents as low as 10^{-9} amperes; combinations of tunnel diodes and transistors in one device from Standard Elektrik Lorenz; a three-terminal variable capacitance semiconductor device described by L. J. Giacoletto of the Ford Motor Co.; silicon solar cells providing piles of up to 15% efficiency, and thermopiles based on silver and antimony tellurides having useful properties up to 500°C; electroluminescent cells of high efficiency, suitable for use in logic circuits and memory systems; and semiconductor disks and plates whose resistance increases by large factors in the presence of magnetic fields.

Micro-electronics

A glimpse into the future was provided by papers on 'solid-state circuits' and 'microminiature circuits'. A. P. Stern of the General Electric Co., Syracuse, pointed out that, besides small size and weight, the objectives of microelectronics include: increased reliability and speed of operation, and reduced power dissipation, cost, and lag between design and production. Analyses of these requirements were used to establish practical values of component packing density which contrasted with some recent exaggerated claims. A. E. Brewster of Standard Telecommunication Laboratories said that the chosen active elements for solid circuits without wires or soldering tags, or separate encapsulation of individual components, should be tiny, robust, cheap, immune to surface effect, of low power consumption, and amenable to mass production. He outlined a gradual approach to complex solid-state tunnel-diode circuits starting with an elementary tunnel diode pair assembled as a three-terminal device. A team of Japanese workers from Tohoku University described semiconductor diodes and triodes designed as impedance and admittance multipliers and inverters.

A monthly review—under basic headings—of the latest control engineering developments for all industries; especially edited for busy technical management, plant and production engineers, chemical engineers, etc., who are not specialized in instrument and control systems

IDEAS APPLIED . . .

. . . to FLOW

Electro pneumatic valve-positioner using magnetic feedback

Control valves for use with electrical systems usually incorporate some form of energy conversion, the power which operates the valve being derived from a source of pressurized fluid. (All-electric operation is not generally used because of the difficulty of combining adequate power with satisfactory speed of response.) The conversion from an electrical signal to fluid power necessarily involves complication. A valve-positioning system recently introduced by British Arca Regulators uses an unusual type of magnetic feedback, and appears to be less complex than most other designs.

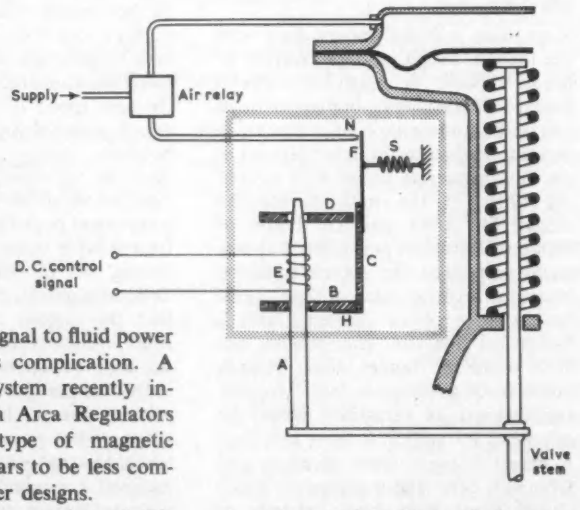


Fig. 1.1 Schematic diagram of valve-positioner using magnetic feedback device. The flapper *F* is held in equilibrium by the spring *S* and the magnetic force acting on *C*. The latter depends on the current in the coil *E* and the air-gap between *A* and *D*

The principle of operation of this positioner can be seen from Fig. 1.1. The armature *A*, in the form of rod tapered at one end, is rigidly attached to the stem of the valve. This armature passes through clearance holes in the stationary iron plates *B* and *D*, and through the control coil *E*. Attached to plate *B* by a flexible metal strip *H* is another iron plate *C*, which is separated from the plate *D* by a small air-gap. The plates *B*, *C*, and *D*, and the portion of *A* between *B* and *D*, form a magnetic circuit, energized by the current in the control coil *E*. The reluctance of this magnetic circuit is determined mainly by the air-gap between *A* and *D*. (The air-gaps between *A* and *B*, and between *C* and *D*, are only a few thousandths of an inch; the diametral clearance between *A* and *D* varies from a few thousandths of an inch to about ¼in, depending on the position of the valve stem.)

The flapper *F* and the nozzle *N* operate in a conventional manner, the air supply to *N* being restricted, and the nozzle feedback pressure being used to operate an air relay supplying the diaphragm chamber of the control valve. Under equilibrium conditions, *F* is held in the required position relative to *N* by the magnetic force acting on *C*, and by the force exerted by the spring *S*, *F* being rigidly attached to *C*. Any change in the control signal fed to *E* alters the magnetic force acting on *C*, and hence alters the clearance between flapper and nozzle. Thus an increase in the control signal produces an increased pressure in the nozzle line, and a consequent increase in the pressure in the valve diaphragm chamber. In the arrangement shown, this moves the valve stem towards the 'closed' position, and increases the air-gap between *A* and *D*. The magnetic force on *C* is therefore reduced, and a new equilibrium position is established in which the pressure on the valve diaphragm just balances the force of the valve return-spring, plus any forces exerted on the valve by the fluid being controlled.

As with other flapper-nozzle combinations, the whole range of feedback pressures corresponds to a change in the clearance between *F* and *N* of the order of 0·001in. Consequently, for the complete range of positions of the valve stem and feedback device, the equilibrium position of *C* relative to *D* changes by only a few ten-thousandths of an inch. The nature of the feedback is thus

governed almost entirely by the profile of the upper part of the armature *A*, and this can be designed to give linear or non-linear response as required.

An interesting feature of this design is that it does not involve the conversion of an electrical control signal to a corresponding air signal. A very small change in the input signal produces full operating power—it is claimed that a deviation of 1% in either control-current or valve-position will cause maximum air-pressure to be applied.

The 'zero' and range of valve movement for a given d.c. input range are determined by the position of core *A* relative to the valve stem, and by the air-gap between *D* and *C*. These are adjustable, so that the working travel of the stem can be located as required within the stroke of the valve.

. . . to CONDUCTIVITY

Measurement by three-terminal transformer ratio-arm bridge

V. S. GRIFFITHS, Battersea College of Technology

The measurement of the conductance of liquids, whether using conventional electrodes or a non-contact system, is often complicated by errors caused by 'shunt' losses due to the capacitance of connecting leads and to stray impedances. For example, a length of coaxial cable may form a large shunt capacitor in parallel with a small-capacitance electrode system. The effects of these

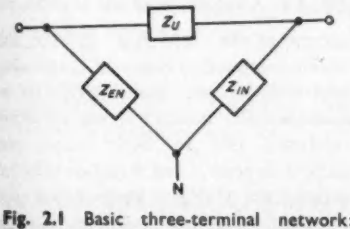


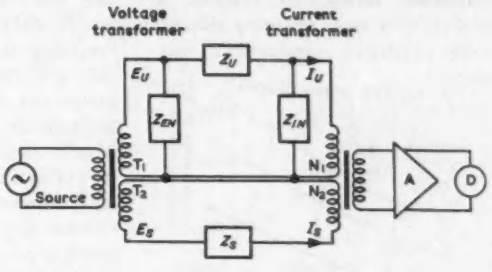
Fig. 2.1 Basic three-terminal network: Z_{EN} and Z_{IN} are the cable impedances, which are connected to the neutral *N*

shunt losses may be eliminated by the use of the three-terminal network described below. In this system, the shunt losses are isolated from the measurement terminals by means of a guard, or neutral, electrode to which the screens of the cables are connected.

Principle of three terminal bridge

Figure 2.1 shows the basic circuit of a three terminal network. Z_u is the impedance to be measured. Z_{EN} and Z_{IN} are the cable impedances, which are

Fig. 2.2 Three-terminal network connected to bridge for comparing the unknown impedance Z_u with the standard impedance Z_s. *A* and *D* are an amplifier and detector, respectively, for detecting the balance condition



connected to the neutral, and consequently removed from the measurement. The neutral terminal can also be used to remove insulation leakage, or to form a defined electric field without 'fringing' lines. Fig 2.2 shows the network applied to the bridge. The voltage transformer provides two ratio-arms with a turns ratio T_1/T_2, providing voltages E_u and E_s (in opposite phase) to Z_u and Z_s, the unknown and standard impedances. The transformer is energized by a 1000c/s oscillator and is constructed with a magnetic shield, so that stray fields will have no effect on the measurement. The resultant currents I_s and I_u are balanced by adjusting Z_s to give zero voltage at the detector. There will then be zero core-flux in the current transformer and

$$N_1 \cdot I_u = N_2 \cdot I_s \qquad (1)$$

Under the conditions of zero core-flux there is zero voltage across the current-transformer windings, and the connexions to Z_u and Z_s on the current-transformer side are at neutral potential. Hence the voltage across Z_u is E_u and that across Z_s is E_s, so that

$$I_u = E_u/Z_u \qquad (2)$$

$$I_s = E_s/Z_s \qquad (3)$$

From (1), (2) and (3)

$$N_1E_u/Z_u = N_2E_s/Z_s \qquad (4)$$

The voltage ratio E_u/E_s equals the turns ratio T_1/T_2 so that equation (4) becomes.

$$Z_u = N_1T_1 \cdot Z_s/N_2T_2 \qquad (5)$$

The two turns-ratios may each be 1000 : 1, leading to an overall ratio of 10^6 : 1.

At balance, neither Z_{IN} nor Z_{EN} appears in the equation. Further, Z_{IN} has no voltage across it and therefore draws no current. Off balance, the effect is to lower the sensitivity by lowering the detector input-impedance, a factor which may be overcome by increasing the gain. The impedance Z_{EN} loads the source, and by drawing current through the source impedance reduces the applied voltage E_u. The measurement, however, depends on the ratio E_u/E_s and not on the absolute voltage. In an ideal transformer this ratio is constant, equal to the turns ratio, and a shunt on one winding reduces the voltages on all the windings by the same proportion. In practice the transformers are not ideal, and shunt errors will arise. Careful construction can reduce the errors to negligible proportions, and in any event the effects can be compensated for.

In practice the unknown is often a complex impedance. Fig. 2.3 shows the bridge where the standard and unknown impedances have been divided into

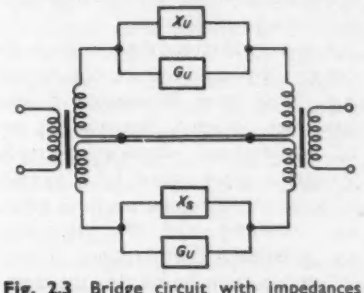


Fig. 2.3 Bridge circuit with impedances split into their reactive and 'conductive' (i.e. resistive) components

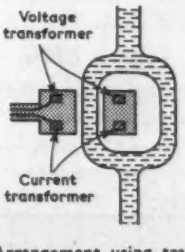


Fig. 2.4 Arrangement using transformers linked by a liquid circuit

reactive components (X) and 'conductive' (or resistive) components (G). Equation (5) can be rewritten in terms of conductances:

$$G_u = (G_sT_2) \cdot N_2/T_1N_1 \qquad (6)$$

If (G_sT_2) is regarded as the standard, then either the conductance may be fixed and the number of turns varied, or the number of turns fixed and the

conductance varied. In practice a combination is used, requiring the use of one standard conductance per

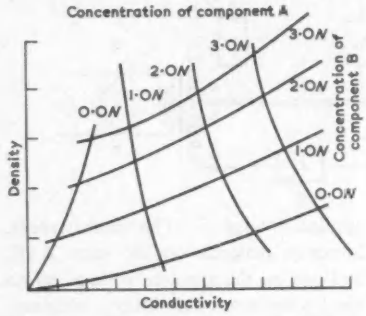


Fig. 2.5 'Carpet' diagram obtained by measuring conductivity and density simultaneously

decade. Similar arguments can be advanced for the reactive components.

Determination of conductance

A bridge is thus available which is capable of measuring either conductances or capacitances of systems remote from the actual bridge, since the capacitance of long leads and spurious impedances connected to the measuring terminals are eliminated.

Using conventional dip-type electrode conductivity cells, results comparable with those from Wheatstone bridges have been obtained. However, the use of conventional dipping electrode systems is accompanied by a number of practical difficulties, many of which are associated with the electrodes, e.g. polarization, absorption, fouling, etc. It has been found that the three-terminal bridge permits the use of non-contacting electrode systems. Consider equation (6) where T_1 and N_1 are made single turns, then

$$G_u = N_2 T_2 G_s$$

The physical nature of the windings is unimportant, and there is no reason

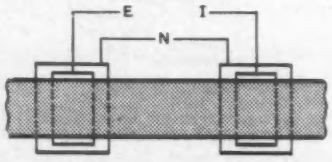


Fig. 2.6 'In-line' arrangement using screened electrodes

why the transformers should not be linked by a closed annulus of electrolytic solution contained within a glass tube. Thus the arrangement shown in Fig. 2.4 may be used; the transformers are wound upon high-permeability, Mumetal, toroidal cores and are linked by means of a glass-loop cell. The transformers are normally moulded into an insulating resin, and where the electrolyte is inert with respect to the moulding, the probe may be immersed directly in the test solution, provided the container is large in comparison with the probe. This type of unit has been used to determine the conductivity of a variety of solutions and has been found to be particularly suited to concentrated solutions, both in static and in flow systems.

Recently it has been found possible to seal the transformers into a glass envelope; this has greatly extended the usefulness of the probe. An interesting application has been the simultaneous determination of the conductance and density of a two-component aqueous solution; conductance is measured by this technique, and density by a float technique. A calibration 'carpet' diagram allows both components to be determined (Fig. 2.5).

Attempts have also been made to measure conductivity with an 'in-line' technique (Fig. 2.6) and it is found that this electrode system works satisfactorily for poorly conductive solutions. The voltage and current electrodes, *E* and *I*, are copper strips wrapped round the tube; the neutral electrode overlaps the working electrodes, the electrodes being separated by insulating material.

Acknowledgment

The author wishes to express his grateful thanks to Messrs Wayne-Kerr Laboratories for assistance received in connexion with the work described above.

. . . to ANALYSIS

Continuous measurement of concentration in a two-component gas-stream

A method of continuously measuring the ratio of the components in a mixture of two gases has been developed by Monsanto Chemicals, using equipment originally designed for gas chromatography. The system is based on a 'gas-density balance' manufactured by Griffin & George, who are now arranging to supply the complete equipment for the new application.

The gas-density balance, in its standard application in gas chromatography, is used to detect the presence of various components of a gas mixture in a stream of 'carrier' gas. (The components are first separated from one another by passing a sample of the mixture through a chromatograph column; this column has the effect of delaying each component by a time which is characteristic of the component, thus allowing it to be identified.) The gas-density balance detects the presence of the components by comparing the density of the gas passed through the column with that of the pure carrier gas. As the density of a two-component gas mixture is directly related to its composition, this equipment is suitable for the analysis of such a mixture, provided that a pure supply of the major component is also available.

The principle of the gas-density balance, originally developed by Martin (*1*), may be seen from Fig. 3.1. A sample of the gas mixture enters at *A*, divides into two streams, following the paths *ABED* and *ACFD* respectively. A

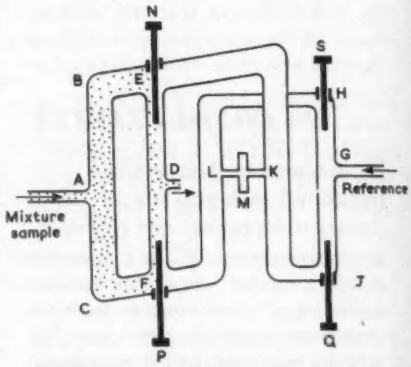


Fig. 3.1 Schematic diagram of the Martin gas-density balance

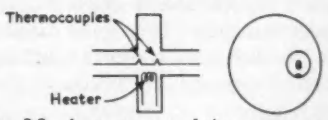


Fig. 3.2 Arrangement of the anemometer

sample of the 'reference' gas (i.e. the major component) enters at *G*, divides, and follows the paths *GHLFD* or *GJKED*. The balance is set up using reference gas in both sides, the adjustable rods *N* and *P* (which vary the resistances of the corresponding gas passages) being positioned so that the alternative paths for the sample gas are of equal resistance. Similarly, *Q* and *S* are adjusted to provide paths of equal resistance for the reference gas. When the equipment is thus balanced, and gases of equal density are being introduced, there is no flow through the anemometer *M*. If the gases are of different densities, a pressure difference exists between *L* and *K*, and there is a flow of gas through *M*.

That this must be so may be seen more easily by regarding the system as being static. (This is, in fact, a fair approxima-

tion as the gas-flows are very small.) If, in the static condition, it were possible for the portion *EBCF* of the apparatus to be filled with a gas heavier than that in the remaining gas-paths, the pressure at *L* would exceed that at *K*; this becomes apparent if the pressure differences round the path *LPCBNK* are considered. While this is a simplification of the true situation, a similar effect is observed under running conditions.

The anemometer *M* (Fig. 3.2) comprises two thermocouples in series, and a heater, placed asymmetrically in a circular chamber. The output from the thermocouples, which depends on the cooling effect of the gas flowing past them, varies approximately linearly with density-difference, up to a value of about 0·1 g/l. The gas mixture ratio (i.e. density-differential) is recorded on a strip-chart potentiometer. Minimum scale range depends on the molecular weight of the gas, but can be as little as 15×10^{-6}g/l, if an amplifier is used before the recorder.

The gas-density balance is made in the form of a copper block in which the gas passages are drilled. This is housed in a temperature-controlled cabinet, which must be kept at a sufficiently high temperature to ensure that both components remain in the vapour state. Pressure regulators are provided on both sample and reference inputs.

A significant point in this design is that the sample gas does not pass through the anemometer. Thus the output from the anemometer does not depend on the heat conductivity of the component being measured.

Reference

1. Martin, A. J. P. and James, A. T.: 'Gas-Liquid Chromatography: the Gas Density Meter, a New Apparatus for the detection of Vapours in Flowing Gas Streams', *Biochemical Journal*, 1956, *63*, p. 138.

. . . to TRANSMISSION

Electrical-pulse system for process variables

A range of measuring and control equipment, designed by Officine Guardigli of Milan and now being produced in this country by R. B. Pullin, uses a signal transmission system which is claimed to avoid many of the disadvantages of both pneumatic and electronic systems. Basically, the method used is to convert the variable to be measured into a mechanical torque; any change in this torque operates an electrical-pulse-generating device, the number of pulses being proportional to the input change. The pulse output is used to operate receiving instruments based on stepping-motors.

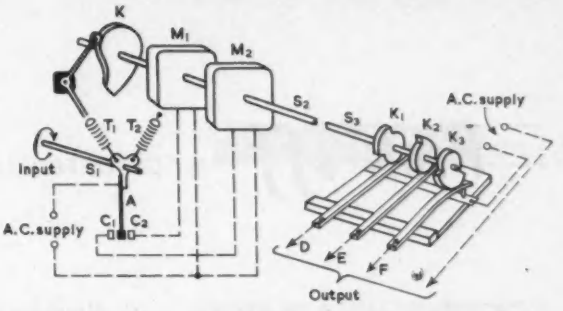


Fig. 4.1 Schematic diagram of pulse transmission system. Changes in the input torque on the shaft S_1 are converted to proportional numbers of electrical pulses on the output lines D, E, and F

The principle of operation of the torque-to-pulse converter may be seen from Fig. 4.1. Under steady conditions, the input torque in the shaft S_1 is balanced by the tensions in the springs T_1 and T_2, so that the contact A touches neither of the contacts C_1, C_2. A change in the input temporarily displaces A to make contact with either C_1 or C_2, so energizing the appropriate unidirectional synchronous motor (M_1 or M_2). The resulting rotation of the shaft S_2 drives, *via* a gear-box, the cams K_1, K_2 and K_3. The synchronous motors also drive the cam K, which adjusts the tension in T_1 and T_2 until the contacts are opened, thus cutting off the motor supply.

Several different measuring devices may be used to produce the input torque. For differential pressure, a mercury-filled H-shaped tube is used, working on a principle similar to that of the conventional ring-balance meter; for pressure, Bourdon tubes, bellows or diaphragms; for temperature, Bourdon tubes operating from mercury-in-steel or gas-filled thermometers. When the torque produced is not proportional to the measured variable, as when using differential-pressure measurements to represent flow, linearization is effected by using the appropriate profile on the cam K.

The output from the converter, when the shaft S_3 is rotating, consists of sequential pulses (with overlap) on the lines *D*, *E* and *F*. These are rectified and fed to the receiver stepping-motor shown diagrammatically in Fig. 4.2. In the position shown, the stator pole P_2 is being energized. P_3 is next energized, before the supply to P_2 is cut off, so that the rotor moves to a position such that R_2 and R_3 are positioned symmetrically between P_2 and P_3. Next P_2 is de-energized, so that R_3 moves fully under P_3. Then P_1 is energized, and so on, so that a rotor pole takes eight steps in moving from one stator pole to the next. Full-scale movement on the circular indicators used with this system is 270°. This corresponds to 327 steps of the the receiver motor; i.e. resolution is approximately 0·3% of the full-scale reading.

The standard control system used with this equipment employs hydraulically-operated valves driven by reversible electrohydraulic motors which are actuated only when valve movement is required. 'Floating' control is normally used, i.e. the valve moves at constant speed in the appropriate direction until the deviation is cancelled. The speed can be preset within the range of 12s to 20min for full valve-movement in either direction. The initial control signal is obtained from a contact system similar to that used in the transmitter, without the force-balance feedback arrangement.

Advantages claimed for the Guardigli equipment are: (1) that the use of a relatively high-level electrical-pulse transmission avoids troubles caused by pick-up and signal attenuation; (2) no specially stabilized supplies are required; (3) most servicing can be done by electricians without special instrument training; (4) many standard parts are used; e.g. the receiving equipment, which is extremely simple, is identical, apart from scale markings, for all variables.

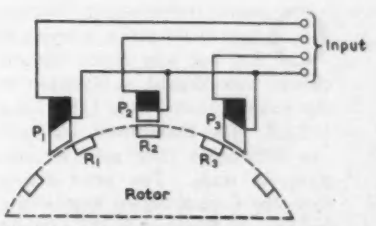


Fig. 4.2 Arrangement of stator poles relative to rotor poles

Pick-off

by 'UNCONTROLLED'

THERE ARE QUITE a few engineers who feel about cybernetics much as the late and unlamented Goering said he felt about culture—at the mention of it they reach for their revolvers. I was accordingly surprised that this subject was chosen for an informal discussion at the Institution of Mechanical Engineers last month, and I went along hoping for either fireworks or illumination. In fact, the meeting turned mainly on the human operator and what he can do. Many delegates argued that the show had been wrongly billed, and should have been entitled 'ergonomics', but the answer was that, like 'automation', 'cybernetics' means all things to all men. Also, since it derives from the Greek for steersman (*kubernetes*), it could be thought to deal with the human being in the control situation.

I was delighted to hear Landon Goodman in crackling form at this meeting. When discussion flagged he revived it with wit, and when it soared too high he persuaded it smoothly back to earth. Toward the end he asked the assembly if they knew any examples of the industrial application of Namur-type cybernetics, and of course no one could take up the challenge.

OXFORD UNIVERSITY'S Department of Education is trying to find out why fewer students choose technological qualification in this country than in the U.S.A. and U.S.S.R. The Department will take two years and a £2500 grant to complete its study. The grant comes from the Capitol Radio Engineering Institute of Washington D.C. (oddly enough), and it will enable the investigators to analyse sixth-form abilities and ambitions. I understand that the Department will assess existing mechanical aptitudes of grammar schoolchildren and compare the technological sectors of British curricula with their American and Swedish counterparts. This is obviously a job worth doing, and I for one shall be most interested in the results. What a pity that it must take two years to get them! A start was made a few weeks ago with a colloquium at Missenden Abbey, led by Mr A. D. C. Peterson who is directing the investigation. Professor M. W. Thring of Sheffield University was among the speakers, and he charged British industry with being the most stick-in-the-mud in the world in its attitude to scientists and technologists. As an example of this backwardness he pointed to the absence of scientists from boards of directors. He also made the now customary complaint that only accountants and financiers find their way to 'success'. I think Professor Thring is right, both about our stuckedness-in-the-mud and the pathways to success, but on the second point we should have to be very precise about our meanings. An engineer may find plenty of an entirely different kind of 'success' and never come within sniffing distance of a board of directors.

I WAS MOST IMPRESSED by last month's demonstration of closed-circuit televisual teaching at Barnhill Secondary Modern School, which has been microwave-linked to Hayes Grammar School two miles away. The present installation (by High Definition Television Ltd, a Pye subsidiary) is used for science lessons only, but it could be applied with varying advantage to almost any subject. As sometimes happens with mechanization and automation, however, it will by no means cut down the number of staff. A teacher must still stand by at the receiving end to keep order and encourage active interest (a microphone with a two-foot parabolic dish is aimed at pupils with questions to ask, and a Post Office telephone circuit does the rest). I was struck by the amount of *extra* work put on the teacher. He must prepare his lesson and all his apparatus down to the very smallest detail, for even a 27-inch screen is not big enough to give him the latitude he is used to. He has in fact to give a television performance for which he has written the script, built the scenery, stage-managed the effects, rehearsed the cast, and in which he plays the leading role. Almost incidentally, he is expected also to discipline and interest his classes and cope with their unscripted questions. Yet this may still be the saving of his kind, for the nation is obviously more willing to pay television performers than schoolteachers.

TECHNOLOGICAL EDUCATION for quite a different age-group came up for discussion at the Royal Aeronautical Society on 16 March. There was a lively meeting on the training of 'guided missiles engineers', and it became quite a tussle between contenders from the Ministry of Aviation, the armed services, industry, and schools and colleges. Speakers from industry seemed to be demanding the trained genius, but said they could not afford the time to let him be trained. Servicemen spoke of their special 'user' problems and added that they could very effectively train their own personnel, thank you. The Ministry viewpoint was that costly development troubles were arising because no one would pay to train people. Cranfield emerged as the only institution providing a fully-fledged civilian course, and this was taken solely by foreign students because no British ones came. Nobody tried to define a 'guided missiles engineer' during all this, though everybody thought the breed could be trained. Systems engineers, on the other hand, were considered to be manifestations of natural growth, not to be fashioned by training. Summing up, the chairman said he would see that something was done about all this. I wish him luck.

OPERATORS SOMETIMES get the better of their jobs by the sort of roundabout means that graduates might not tumble to. I heard a rather pleasant story recently of the technique used by certain process workers at high-explosive plants. Apparently the nitroglycerine fumes do something to brain cells, and the result is a splitting headache. Men in the works become 'acclimatized' and remain immune as long as they are continuously on duty, but a short holiday is enough to remove the resistance they have built up. For three days after each break they must suffer acutely. Their elegant solution to this problem is to carry a little bit of n.-g. in their cap-bands when on holiday. Newcomers to the job get advice which is a neatly twisted version of a well-known advertising slogan: if you *don't* want to get a head, get a hat.

DATA SHEET 22

Graphical techniques for control systems – 8

N. G. MEADOWS

Wimbledon Technical College

In this data sheet a procedure is outlined whereby the time constants of a position control system can be determined from the closed-loop transient response, providing it is possible to adjust the controller gain so that the system executes a steady-state sustained linear oscillation. The method is applicable to systems characterized by open-loop transfer functions of the type

$$\frac{\theta_0}{\theta} = \frac{K}{p[p+a][p+b]} \qquad (1)$$

where K is the controller gain, a and b being the inverse time constants. Higher-order systems can be analysed by an extension of the technique to be described.

Method

With the system on closed loop, the controller gain is set so that the output position executes simple harmonic motion (s.h.m.) in response to a small input step. The linearity of operation may be assessed, if desired, by observing the variation of output wave-form and frequency for various magnitudes of the input step.

The error transient is recorded, with several cycles of the ensuing steady-state oscillation, from which the periodic time T and hence the angular frequency $\omega = 2\pi/T$ are determined. The steady-state sine wave is projected back to the origin and subtracted ordinate by ordinate from the error wave-form, thereby isolating the decaying transient term, as indicated in the figure. The isolated transient has a single time constant T_1, which is determined in the usual manner by drawing the tangent from the origin and determining the time at which the tangent line cuts the time axis. The time constants $1/a$ and $1/b$ are then given by

$$\alpha = \frac{1}{T_1}\left[1 \pm \sqrt{1-(2\omega T_1)^2}\right] \qquad (2)$$

where the use of the positive root gives $\alpha = a$ and the negative root gives $\alpha = b$. Hence the time constants are determined from measured values of T_1 and ω.

Theory

Since the closed-loop transfer function is

$$\frac{\theta}{\theta_i} = \frac{1}{1+\theta_0/\theta}$$

then, using equation (1)

$$\frac{\theta}{\theta_i} = \frac{p[p+a][p+b]}{p^3+[a+b]p+abp+K} \qquad (3)$$

For gain K set to give the s.h.m. condition, the denominator must contain a term of the form $(p^2+\omega^2)$ where ω is as previously defined. If $(p+A)$ is the third factor of the cubic in the denominator of equation (3) then

$$[p+A][p^2+\omega^2] = p^3+[a+b]p+abp+K \qquad (4)$$

Equating coefficients gives

$$A = a+b \qquad (5)$$

$$\omega^2 = ab \qquad (6)$$

The time response $(\theta)_t$ to a step input is of the form

$$(\theta)_t = Pe^{-At} + R\sin(\omega t+\phi)$$

where P, R and ϕ are known from the appropriate partial fractions. As the transient Pe^{-At} has been isolated graphically then $A = (a+b)$ is known, as also is the product ab, since ω is known.

Hence

$$1/T_1 = a+b \qquad (7)$$

and in using equation (6) the equation

$$1/T_1 = a+\omega^2/a$$

is obtained. Solving this as a quadratic in a yields

$$a = \frac{1}{T_1}\left[1 \pm \sqrt{1-(2\omega T_1)^2}\right]$$

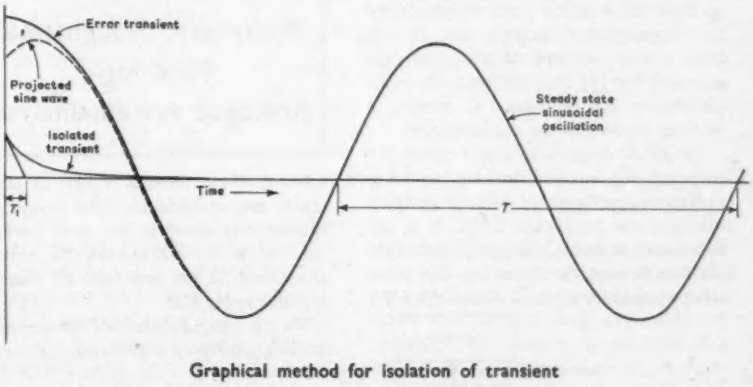
which is equation (2) with a replacing α. It is easily verified that the positive and negative roots give a and b respectively. If, e.g.,

$$\frac{\theta_0}{\theta} = \frac{K}{s[s+2][s+6]},$$

then $\omega = \sqrt{12}$ and $T_1 = 1/8$, on substituting in (6) and (7). $\therefore \alpha = 4[1 \pm \frac{1}{2}]$ from (2), so that $\alpha = 6$ or 2, the given inverse time constants.

With the method outlined, the time T_1 must be very carefully determined if $(2\omega T_1)^2$ is near unity.

In a subsequent data sheet further methods for determining system time-constants will be described.



Graphical method for isolation of transient

Our American correspondents' contribution this month includes news of fluid logic devices used for binary addition

Look at America

Numerically controlled 'draughtsman'

The effective use of modern high-speed digital computation equipment to aid the design process and actually to automate the mechanics of drawing, is rapidly becoming a reality rather than a mere possibility. Numerical control has drastically reduced the production time for parts of complex geometry, but until recently the time required to prepare working drawings for shopmen and inspectors has essentially remained the same.

By modifying a high-speed microfilm printer, the Stromberg Carlson Divn of General Dynamics has produced an automatic drawing machine that turns out a working print in less time than is required to make the magnetic tapes which control the programmed machine tool (*1*, *2*). Once a part has been designed and programmed for the machine tool, the same information can be utilized to produce a working drawing in less than a second.

The block diagram in Fig. 1 shows the evolution of a working drawing beginning with the designer's sketch. After the designer completes the conceptual design, it is put into numerical form so the part programmer can then convert the sketch into the automatic programming tool system (A.P.T.) language. Using A.P.T., a programmer converts a parts configuration into algebraic form and then puts it into computer format. The computer then calculates the tool cutting-path and reproduces it on magnetic tape. This tape (No. 1) is passed through a post-processing subroutine that converts the general information into specific data on another tape (No. 2) for the particular control system on the machine. Tape No. 2 runs the machine tool. Tape No. 1 runs through another post-processing subroutine which makes a tape to program the SC-4020 high-speed printer. The drawing is made automatically and displayed on a high-resolution, high-intensity cathode-ray tube. A 35mm camera is used to photograph the cathode-ray tube image and subsequently drawings are made from the film record. The finished drawing contains an outline of the part and all essential manufacturing data.

THIS MONTH

Automatic draughtsman
Fluid logic
Analogue system-analyser

The obvious advantage of the automatic drawing procedure, when numerical control is used, is that the drawing is made automatically from the same input information as that required by the machine tool. Automatic drawing in this case seems to be easily justified economically. The question which remains is whether or not such a system will be economically feasible where numerical control is not involved.

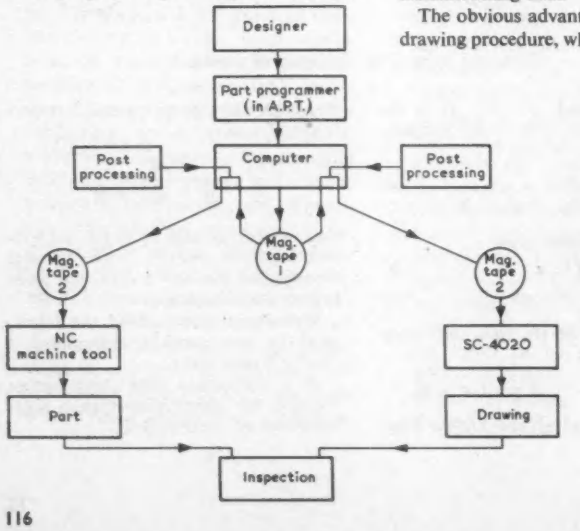


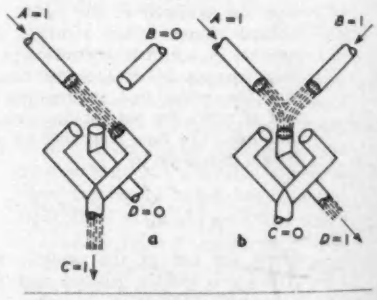
Fig. 1 Schematic diagram of automatic drawing machine, showing sequence of operations from the designer's sketch to the working drawing

Fluid binary logical 'add' device

Growing interest in fluid amplifiers and logic elements with no moving parts is evidenced by recent laboratory work at the Massachusetts Institute of Technology, concerned with the development of a fluid logic element for adding binary numbers (*3*, *4*). Much like the jet relay devices developed at the U.S. Army's Diamond Ordnance Fuze Laboratory,* these logic elements operate on the principle of momentum exchange between two fluid streams as they impinge on each other. Thus far, only devices which perform the 'carry' operation of binary addition have been tested. These elements are commonly termed 'half-adders'.

Fig. 2a shows schematically how two fluid streams can be added. The presence of flow is interpreted as 'unity' whereas no-flow is called 'zero'. 'Addition' of the two-fluid stream constitutes the addition of two one-digit numbers. For example, if stream *A* has a signal (*A* = 1) and stream

Fig. 2 Method of adding two one-digit binary signals



* See *Control* 1960 (Aug.), p. 111

B has no signal ($B = 0$), then the outputs C and D will indicate the binary sum of A and B, or in other words, $C = 1$ and $D = 0$. If the input signals A and B are reversed, the output binary sum is still the same. Alternately, if both A and B are 'unity' (Fig. 2b), the output $D = 1$ gives the binary sum of A and B. Plastic models of these elements have been successfully tested using Univis J-43 hydraulic oil with flow ratios ranging from 7 : 1 up to 20 : 1 and with supply pressures of 4 lbf/in² to 25 lbf/in².

The addition of numbers of more than one digit is made possible by using a cascaded combination of the elementary elements as shown in Fig. 3. External logic is utilized to set the button valves, so that two four-digit binary signals, 0101 and 1101, can be added. The cascade of logic elements thus performs the 'carry' operation of addition, giving the sum 10010.

Proper impedance matching between

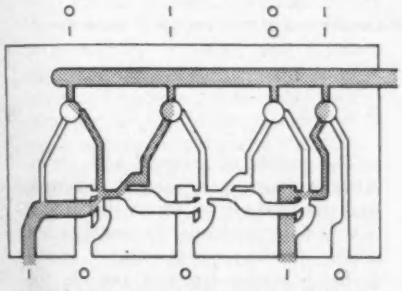


Fig. 3 Addition of binary signals 0101 and 1101

interconnected elements is one of the major problems confronting the user of the elements. However, success with the cascaded 'half-adder' leads one to believe that elements can also be properly matched to form a complete adder.

Analogue analyser for non-linear systems

One of the most powerful techniques used in non-linear systems analysis is the describing-function approach. Underlying assumptions on which the validity of the describing-function technique depends are; (1) the system is separable into a linear part and a non-linear part, and (2) the linear part of the system serves as a sufficiently good low-pass filter, so that transmission of higher harmonics is negligible compared to transmission of the fundamental. In particular, the describing function of a non-linear element is an equivalent amplitude-dependent linear transfer function. The describing function method thus involves a frequency-response analysis of a particular non-linear system based on the amplitude and phase of the fundamental component in the output, as referred to an input sinusoid.

A unique analogue analyser has recently been developed, which automatically solves

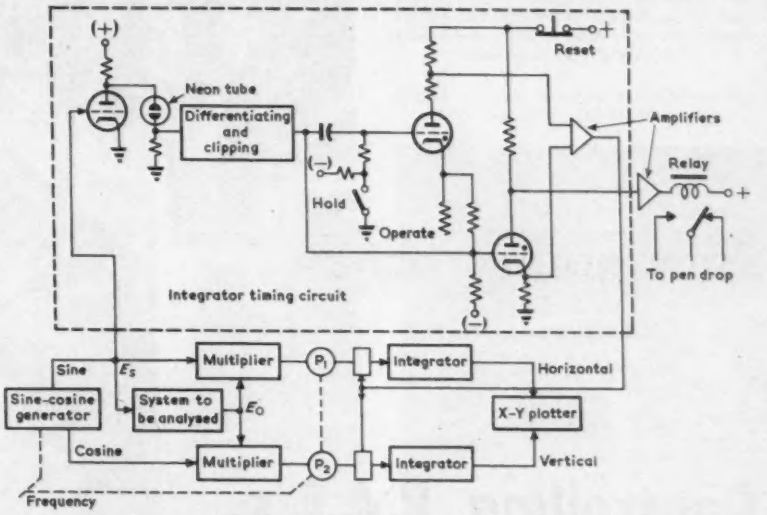


Fig. 4 Schematic diagram of analyser

for the coefficients of the fundamental terms in the Fourier representation of the in-phase and quadrature components of the output wave-form (*5*):

$$A_1 = \frac{1}{\pi}\int_0^{2\pi} E_0 \sin \omega t \, \mathrm{d}(\omega t) \qquad (1)$$

$$B_1 = \frac{1}{\pi}\int_0^{2\pi} E_0 \cos \omega t \, \mathrm{d}(\omega t) \qquad (2)$$

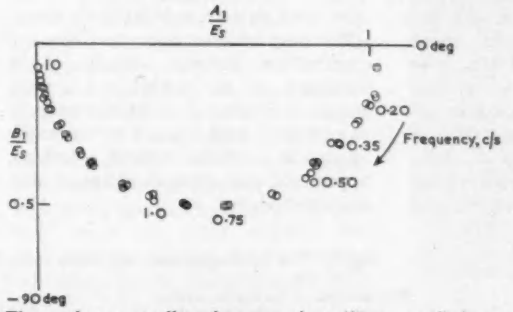


Fig. 5 Plot made by analyser of simple lag transfer characteristic

The analyser actually solves equations (1) and (2) simultaneously, and produces d.c. voltage outputs proportional to the coefficients. If these analyser outputs are read out on an X-Y recorder, the result is a conventional polar plot of amplitude at various phase angles, with frequency varying along the locus.

Fig. 4 shows the scheme of the analyser which, for convenience, was built from standard analogue computer components. Provisions have been made for both continuous and discontinuous modes of operation. In the former mode, a continuous plot is made, but no information is charted which would allow a determination of frequency at particular points on the locus. In the discontinuous mode a special timing circuit stops the integration after one cycle of the input frequency. The voltage held and accumulated by the integrator is then plotted by means of an automatic pen-drop circuit. The integrator, as well as the frequency and amplitude of the input, must then be reset by the operator before the next point can be plotted. A neon tube coincidence circuit serves as a controller to start the integrators, and then stop them after time has elapsed equal to the period of the input wave.

An indication of the accuracy and meaningful frequency range of the analyser is evident in Fig. 5. Here the analyser was applied to a simple lag network, whose polar plot is known to be a semi-circle. The closely grouped sets of points are repeated runs for the same amplitude and frequency. The accuracy, of the order of a few per cent, is comparable to that of a conventional analogue computer using the same components.

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CONTROL IN ACTION

Controlling R.A.E.'s Mach-5 tunnel

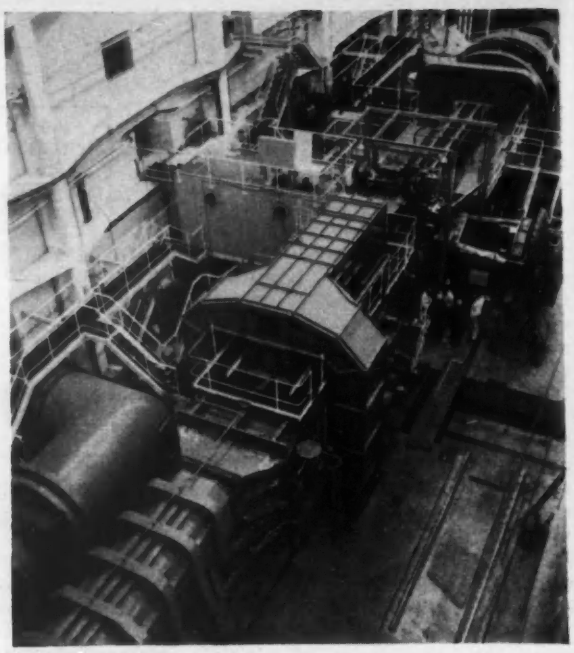


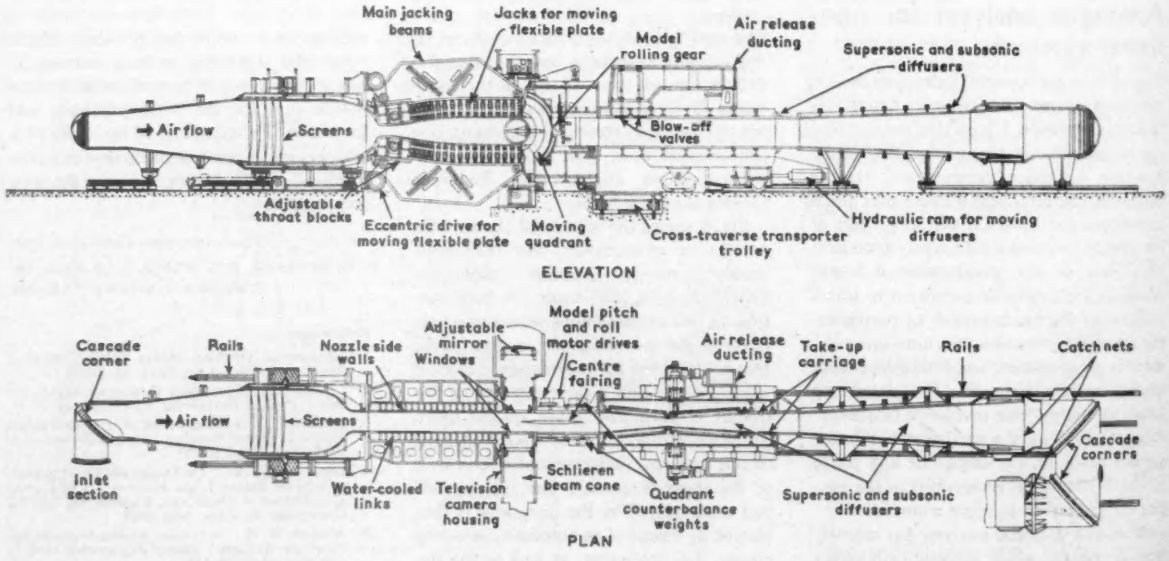
Fig. 1 View from the outlet end of the new R.A.E. wind tunnel

New high-supersonic-speed wind tunnel at Bedford

WIND SPEEDS IN THE RANGE BETWEEN Mach numbers 2·5 and 5 will be available with a new 4ft by 3ft closed-circuit wind tunnel at the Royal Aircraft Establishment, Bedford, which was officially opened on 24 March by the Minister of Aviation. At present the tunnel has a nozzle of fixed throat-gap and contour giving a nominal air speed of Mach 4, but G.E.C., who received the £1m-plus contract for the working-section leg of the tunnel and its associated servo-controls, are to install a flexible-plate nozzle which will provide the Mach 2·5—5 range. The working-section leg (Fig. 2) is over 150ft long and comprises the inlet and contraction sections, nozzle, bridle structure (as the tunnel has a fixed nozzle at present, a temporary anchoring point is used instead of the bridle structure), model-support section, supersonic and subsonic diffusers, and an outlet section.

The rigging of a model with its instrumentation is a lengthy business, and the method by which this tunnel allows for one model to undergo test while, simultaneously, another model is being rigged for test outside the tunnel, is of some engineering interest. The arrangements for the mounting, manipulation and instrumentation of models are incorporated in separate and interchangeable model-support sections or ' trucks ' (Fig. 3), which can

Fig. 2 The working-section leg of the tunnel



be disconnected and removed bodily from the air circuit to an adjacent rigging bay.

Another feature is that the whole of the working-section leg is anchored at a single point, the model-viewing position, and both upstream and downstream of this point the various casings are mounted on wheels running on rails. This allows the tunnel to be opened to change a model-support section, and also accommodates any thermal expansion consequent upon work at high temperatures.

Nozzle control

The maximum inlet pressure will be about 12atm abs. and, to prevent liquefaction in the nozzle at high Mach numbers, the temperature of the air will be allowed to rise to 150°C. Under some operating conditions the pressure in the tunnel may be below 0·1atm abs. It was considered inadvisable for the nozzle-control devices to be enclosed within a pressure shell, so there will be a sliding seal between the fixed and moving walls of the nozzle. This is a double seal, packed with dry air to prevent the ingress of moist atmospheric air into the circuit.

Essentially the nozzle will comprise two fixed side-walls and movable top and bottom walls. Each moving wall is carried by a pair of beams pivoted at the downstream end. Upstream, each pair of beams carries a throat block of fixed contour which is driven upwards and downwards to vary the throat gap. The variable-contour top and bottom walls of the divergent sections of the nozzle are formed by flexible plates each attached to one of the throat blocks at the upstream end, and also to the supporting beams through seventeen pairs of motor-operated ball-screw jacks.

The information required to control the position of the flexible plate at the jack stations throughout the Mach range, is provided by cams mounted on a sliding table in the nozzle controller (Fig. 5). When the operator selects a Mach number, the sliding table is caused to traverse a distance proportional to that Mach so that the cams operate a number of sensing heads, each head driving a magslip transmitter. A coincidence magslip transmitter is connected directly to the flexible plate at each jack attachment point. The difference between the settings of the two magslips results in an error signal which supplies power to drive the jack motor, and consequently the flexible plate, to the position corresponding to coincidence of the two magslips. The system also compensates for variations in jack length with temperature, and permits small corrections to be fed in by follow-through magslips. The dimensions of the throat can be varied in this way from 18in by 3ft at Mach 2·5, to 1¼in by 3ft at Mach 5.

The flexible-plate nozzle will have its downstream end fixed into the bridle structure which will be the only part of the working-section leg anchored to the foundations. The bridle structure will house the high- and low-temperature viewing windows, each lit so that a remotely-controlled 625-line Pye television system may view the model. Windows for high- and normal-temperature viewing will be interchanged hydraulically. At present, with the fixed nozzle, low-temperature viewing windows and Schlieren viewing equipment are used.

Model control

The model-support structure, on which the models to be tested are mounted and manoeuvred in the airstream, can be removed from the tunnel and taken to an adjacent rigging bay on a motor-driven cross-traverse transporter, and another model-support structure or the 'calibration' section, can be inserted in its stead (Fig. 4). In order to remove such a section from the air circuit, casings downstream of the nozzle are moved hydraulically a distance of 11ft axially so that the model-support section can be positioned over the transporter.

The main components of the model-support section are a moving quadrant and the sting shaft on which the model is mounted. The quadrant enables the pitch of the model to be varied within the limits of 5° depression and 27° elevation, while the sting can rotate the model through ±180°. These movements can be remotely controlled when the model-support section is in the line of the tunnel. When a section is in the rigging bays, it is sometimes necessary to reproduce the movements of the sting which occurred when the section was in the tunnel, and portable control cabinets are used for this purpose.

Similar in shape and dimensions to the model-support section, and interchangeable with it in the air circuit, is a calibration section. In this the moving quadrant and sting are replaced by a probe housing which has a 2ft traverse across the airstream. Inside this housing are two hollow

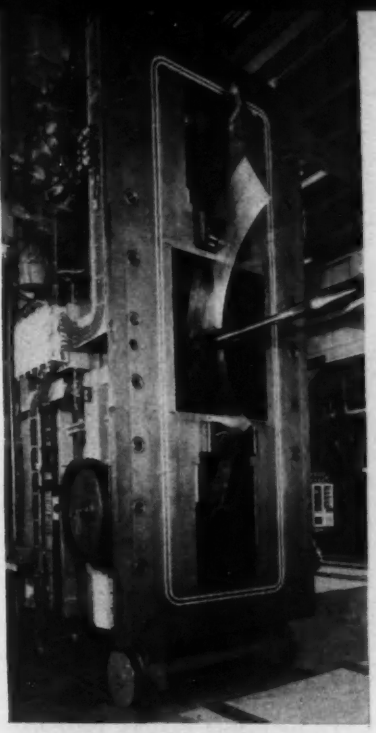
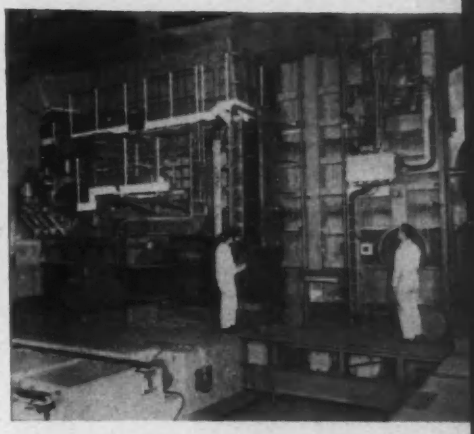


Fig. 3 (left) Model-support section in the rigging bay adjacent to the tunnel. A cross-traverse transporter enables model-support sections to be interchanged

Fig. 4 (below) Inserting a model-support section in the tunnel



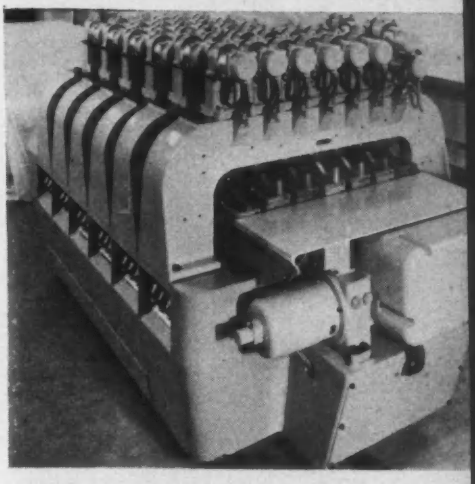


Fig. 5 The nozzle controller employs cams for controlling the position of flexible plates forming the variable-contour walls

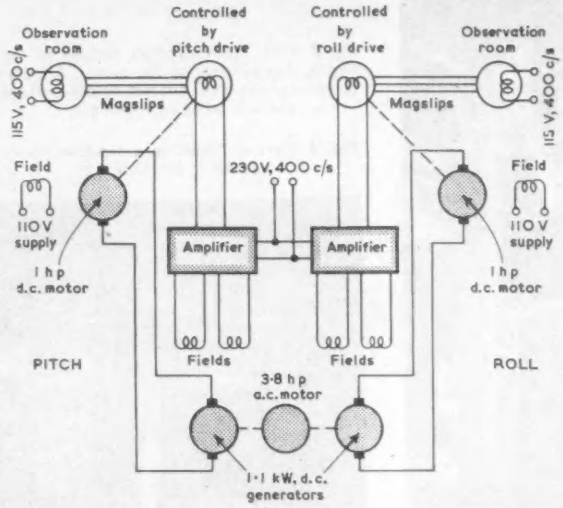


Fig. 6 Model pitch and roll control is on the Ward Leonard principle

probe arms carrying a common probe head fitted with pitot tubes and yaw meters. The probe head may be moved 3ft upstream and downstream of the window centre-line, so that a plot of the airflow can be made in the vicinity of the model.

Remote control of the model under test is provided for both pitch and roll, and, as can be seen in Fig. 6, is based on the Ward Leonard principle. A single 3·8hp induction motor drives two 1·1kW d.c. variable-voltage generators each of which supplies a 1hp separately-excited d.c. motor, one driving the moving quadrant and the other the sting. The control arrangements for speed and position of both quadrant (pitch) and sting (roll) are identical.

The moving-quadrant control system is based on balancing a magslip coincidence transmitter actuated by the quadrant, with a magslip transmitter in the observation room and under the control of the operator. Under conditions of equilibrium equal currents pass through the opposing fields of the 1·1kW d.c. generator supplying the 1hp quadrant-driving motor. If, however, the operator alters the position of the magslip transmitter, which is calibrated in angles of depression and elevation, an error signal is introduced into the magslip system, this signal being fed, *via* a transistor amplifier, to the opposing fields of the d.c. generator. The current in one field increases and in the other decreases, the resulting output of the generator being applied to the quadrant-driving motor which rotates in the required direction until coincidence of the two magslips is re-established.

The control circuit includes such refinements as coarse and fine magslips, a tacho-generator geared to the quadrant drive to assist stability and permit precise speed control, a position-error indicator, and a digital display and read-out system.

Diffuser control

In order to obtain the maximum working efficiency of the tunnel, the speed of the air emerging from the nozzle is reduced gradually, with the minimum loss of energy, by supersonic and subsonic diffusers, before being recirculated through the tunnel *via* the compressors.

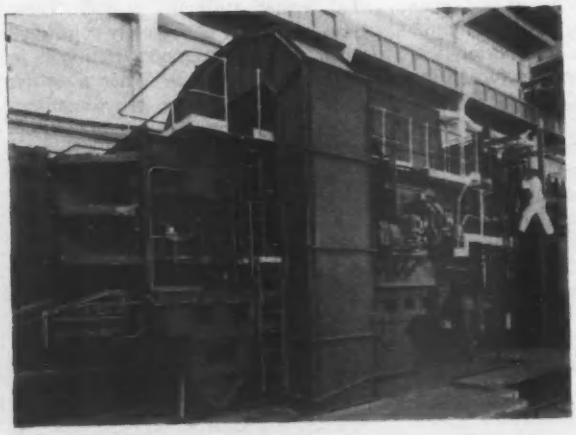


Fig. 7 The supersonic diffuser can be moved 11ft downstream by a hydraulic motor. Note mechanism for operating ball-screw jacks of the moving plates diffuser's and, far right, the model-support section

The supersonic diffuser (Fig. 7) consists of a rectangular-section pressure shell having fixed top and bottom plates. Each side wall comprises a short (fixed) entry-plate, two long plates with a free centre-hinge, and a short plate moving on hinges parallel to the centre line of the tunnel. The free hinge on each side wall is driven by an electric motor through gearing and a ball-screw jack to form an adjustable throat. The electrical control system for the moving plates is similar to that of the model-support section except that the motors and generators are somewhat larger. The plates can be controlled manually, or automatically by the nozzle controller mentioned earlier.

Two 22in quick-acting blow-off valves are incorporated in the supersonic diffuser to limit a build-up of pressure above atmospheric in the event of a flow break-down.

Downstream of the supersonic diffuser is the subsonic diffuser, where the 4ft by 3ft section of the tunnel is transformed to circular shape to match the 7ft diameter outlet casing. The latter is U-shaped in order to turn the airflow through 180°, and the closed circuit is completed through the compressors.

The compressor plant, which provides 88,000hp, is by A.E.I., together with its various motors, gears and control equipment. It comprises two motor-driven sets operating in parallel, each set consisting of low- and high-pressure units which, in series, give an overall pressure ratio of 17 : 1. Each set is primarily driven by a 34,000hp synchronous motor running at 3000 rev/min when connected to the grid, or at any speed between 2160 and 3000rev/min when connected to R.A.E.'s own gas-turbine-drive generators.

To start the system, and also to provide an additional 10,000hp, each set is also driven by an induction motor through a speed-increasing gear-box. This induction motor is controlled by a liquid regulator. As sub-contractors to A.E.I., Harland Engineering provided air-circuit rotating plug-valves, and J. Blakeborough & Sons air-circuit and cooling-water gate-valves.

Observation room

The main controls for the working-section leg are housed in a control console and a correcting panel in the observation room. The console carries model-attitude controls (pitch and roll), mimic indicators showing the side and front elevation of the model itself in silhouette, and two

four-digit indicators which give the angles of pitch and roll.

Separate, but similar, sets of controls and equipment for the flexible-plate nozzle and supersonic diffuser are also included on this control console. Means are provided for controlling the two throats' movement and their positions are shown by four-digit indicators and silhouette-type mimic indicators. On top of the console are 38 error indicators covering all the servo systems of the flexible-plate nozzle, including two for the throat opening, 34 for the plates' jack-stations and two for the plate-inflexion points. Behind the console is the correcting panel which incorporates plate-curvature and correction indicators together with the controls required to inject corrections into the flexible-plate jack-station servo-mechanisms.

Basic servo-amplifiers are used in the electrical control circuits of the flexible-plate jacks, but some of the other servo-mechanisms employ modifying units as well. These are mounted in racks in the data-reduction room. Various G.E.C. digitizers indicate the position of certain wind tunnel components in digital form. Each digitizer consists of a head geared to the controlled member, a decoder located in the data-reduction room, and a four-digit indicator in the observation room. Digitizing equipment is fitted to the model-sting, nozzle throat, supersonic diffuser and calibration probe.

CONTROL IN ACTION

Governing engine-driven alternators

Diesel-powered a.c. generating equipment regulated electrically

A HIGH SPEED OF RESPONSE TO LOAD changes is understood to be obtained from Ardleigh Engineering's 500 MkII (electric) governor, which is now being employed to regulate the operation of a number of Davey Paxman a.c. alternator sets. However, the governor can, in fact, be used to regulate the operation of sets driven by any type of prime-mover, and any number of sets can be run as single units, or in parallel, as desired.

Basically the equipment consists of a 'pilot' alternator which is driven by the prime-mover, an amplifier unit, a hydraulic pump unit, and a fuel rack—or throttle—actuator. Broadly, the governor operates by accepting speed signals from the engine-driven pilot alternator, in combination with main-alternator-load signals, to control the fuel-rack actuator which regulates the fuel supply to the engine.

Throttle actuation

The fuel rack actuator, which is normally mounted on the engine somewhere convenient for operating the throttle-control linkage, is an electro-mechanical servo-mechanism which converts the electrical error signal into a mechanical movement. It is fed with oil at 250 lbf/in² from a hydraulic oil pump unit, which is normally driven by the engine under regulation, although a separate electric motor may be used. The actuator provides a rotating-shaft output, although a smaller version having ram or rotating output is available. The latter may have a vertical or horizontal shaft, and clockwise or anti-clockwise motion to increase fuel.

The prime-mover is arranged to drive a permanent-magnet pilot alternator at 3000rev/min, the latter's output—30VA, 120V, 400c/s—being used both to power the amplifier unit and also provide a measure of the prime-mover's speed. The use of a pilot alternator has a number of advantages. It ensures a continuous supply to the amplifier; if the main alternator performed this duty, a momentary short-circuit would interrupt the supply to the amplifier. Furthermore, when starting a closely-regulated main alternator of modern design, it takes longer for the voltage to build up to full output than for the engine to reach full speed. In other words, if the information feed were from the main alternator instead of from a pilot alternator, the governor could not take over control at the proper moment. Another advantage of the pilot alternator is that its output frequency of 400c/s gives the governor a faster response than would operation from the 50/60c/s main alternator.

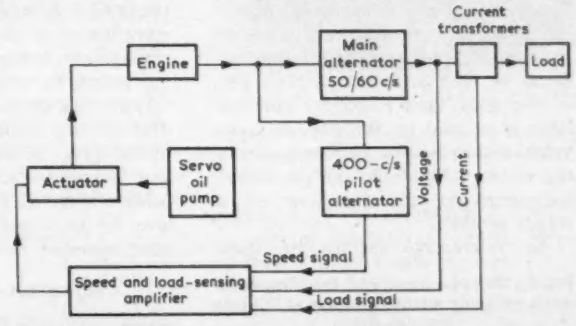


Fig. 1 Governing is by a combination of engine-speed signal (from the pilot alternator) and load signal (from the main alternator)

Operation

As can be seen in Fig. 1, the output of the engine-driven pilot alternator (the speed signal) is fed to the amplifier unit, where its frequency, which is, of course, proportional to the speed of the engine, is measured. The measuring circuit produces a d.c. signal of a value proportional to the deviation in frequency from the desired datum.

The electrical output (wattage) of the main alternator is measured by a load-sensing unit which is fed from three current transformers (one per phase) fitted over the output cables from the alternator, and also with phase voltages *via* cables connected to each phase and neutral. In this way the load-sensing unit produces an output proportional to power.

These two signals, speed deviation (from the pilot alternator) and load, are combined and amplified in a magnetic amplifier within the amplifier unit, and fed to the throttle actuator.

The actuator produces a mechanical movement proportional to the output of the amplifier. It follows that when the alternator is running at the desired speed under a steady load, the throttle is in some given position appropriate to the load, and the speed is correct.

If, however, the load on the alternator increases, the load-sensing unit transmits signals to the effect that the throttle should open; furthermore, if a speed change should occur, the pilot alternator signals this to the alternator. Any reduction in load will lead to similar action, although here the result is, of course, to decrease the amount of fuel injected.

It is claimed that the throttle will start to move to a new position as a change-of-load commences, and that this thottle movement occurs before the speed of the engine has changed to any great extent. Any deviation in speed is understood to be mainly due to slight inaccuracies in the new throttle-setting as demanded by the load signal, together with the effect of a small time delay in operating the throttle. Such a speed deviation would, of course, be signalled by the pilot alternator, and in consequence the throttle would be trimmed to a new position in order to bring the speed back to the set value.

When starting a governor-controlled Diesel engine, the fuel racks must first be opened a certain amount, and this may be done manually or automatically using a solenoid arrangement. As soon as the oil supply to the actuator has reached the correct pressure, and the engine has reached operating speed, the governor will take over. For automatic starting, the solenoid can be switched out by a centrifugal switch which may be arranged to open at a predetermined speed. It follows that solenoid-starting can be remotely operated.

Performance

According to the manufacturers, the fact that the position of the engine's throttle is determined by the load on the alternator, and not by the engine's speed, gives the governor a high speed of response. Droop is adjustable between 0 and 5%, and negative droop can be provided. The sudden onset, or cutting off, of full load is understood to give speed transients of less than 2%, and recovery to the set value within 1s, when adjusted to zero droop. The frequency stability when under a steady load is given as $\pm 0{\cdot}25\%$. Two or more alternators can be operated in parallel, with automatic load sharing—the proportion of the load handled by each machine can be adjusted while on load, and this load ratio maintained for all values of total load. The system is thus said to provide an output of constant frequency irrespective of load or the number of alternator sets being operated in parallel.

CONTROL IN ACTION

Automatic weighing at Walters Biscuits

Pneumatics and hydraulics aid foods packaging

AT THE ACTON WORKS OF WALTERS Biscuits Ltd, batteries of Fluidflow automatic weighing machines are employed in producing 12-dram packets of 'potato puffs'. Manufactured by George Driver & Sons Ltd, of Wembley, these Fluidflow machines have been used by Walters for many years, and provide a good example of the value of hydraulic and pneumatic techniques in the handling of a fragile product.

An interesting feature of these machines is their use of a vibratory feeding action which is hydraulically operated. A motor-driven hydraulic compressor is incorporated in each machine, the compressor's shaft carrying eccentrics which cause reciprocatory motion of two 'driving' pistons. The driving cylinders are connected by oil-ways to two 'receiver' pistons and cylinders, each receiver piston being connected through a bell-crank lever to the vibratory feed trough. A hand-operated control valve on the compressor enables one to vary the amplitude of the vibratory motion in order to adjust the rate of feeding.

Fig. 2 shows the operation of a Fluidflow automatic weigher. The product ('potato puffs') is fed along the vibrating chute into a weighing pan. When twelve drams of product have been delivered, the weighing pan falls and in so doing operates a microswitch. The circuit thus made, opens diaphragm valves within the hydraulic unit, so that the pressure collapses and the vibratory feed from the chute is halted. Simultaneously, the microswitch energizes a solenoid valve which allows compressed air to escape through a series of holes in a tube situated near a metal flap in the weigh-pan. The escaping air lifts the flap, and then blows the weighed product against a Perspex guard, from whence they fall into an open bag.

Two Atlas Copco compressors provide the compressed air for these Fluidflow machines. Driven by a ¾hp electric motor, each unit has a piston displacement of 4·4ft³/min, and both machines are regulated to cut out at 55lbf/in², and in at 40 lbf/in²—an arrangement which gives a sufficiently stable pressure for satisfactory operation.

Fig. 1 One of a battery of Fluidflow automatic weighing machines in use at Walters Biscuits, Acton

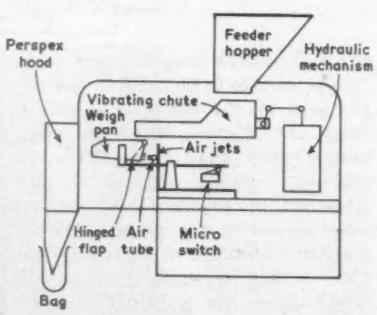


Fig. 2 The product—'potato puffs'—is fed along a hydraulically-vibrated chute into a weigh-pan. When twelve dram have been delivered, the pan falls and operates a microswitch, so halting the feed and allowing compressed air to eject the weighed product into an open bag

NEWS ROUND-UP

from the world of control

BUSINESS

Sperry Europe formed

A new organization, Sperry Europe Continental Co., with main offices at 7 Avenue de L'Opéra, Paris, has been formed to handle the sales and servicing of Sperry equipment in Western Europe. The new firm will represent both Sperry Gyroscope Co., Division of Sperry Rand Corp., U.S.A., and Sperry Gyroscope, Brentford, in the negotiation of patents, licences and contracts throughout Europe. Its President and Director General is René Laureau, who formerly headed his own company, Société d'Equipments Aéronautiques Laureau. Colin A. Richardson, formerly Aeronautical Sales Manager of Sperry, Brentford, has been appointed Marketing Director. Peter P. Ehrhardt, who is organizing a Munich office, will be the consultant and sales representative in Germany, and Sidney J. Reid, the representative for Switzerland and Belgium has offices in Lausanne.

Solartron's Russian order

A contract has been signed between V/O Mashpriborintorg, Moscow, and Solartron for the supply of apparatus to the value of over £84,000. The order includes two automatic X-ray fluorescent spectrometers, three digital-data recorders, digital voltmeters, and other electronic instruments.

E.E.A.'s council

The new Chairman of the Council of the Electronic Engineering Association is Dr D. N. Truscott, General Manager of G.E.C.'s Electronics Division, in succession to L. T. Hinton of Standard Telephones and Cables. W. D. H. Gregson, Assistant General Manager of Ferranti's Scottish factories, is now Vice-chairman, in succession to R. R. C. Rankin of Mullard Equipment. The Council now includes representatives of the Electronic Apparatus Division of A.E.I., Decca Radar, E.M.I. Electronics, Elliott Brothers, Ferranti, G.E.C., Kelvin & Hughes, Marconi's Wireless Telegraph, Mullard Equipment, Murphy Radio, Plessey, Pye Telecommunications, Redifon, and Standard Telephones and Cables.

Hawker Siddeley partnership

The electronics sections of Armstrong Whitworth Aircraft and Brush Electrical Engineering have been linked to form a partnership, known as Armstrong Whitworth/Brush, to manufacture and market electronic and electrical control and intelligence systems. Brush will handle marketing in co-operation with Armstrong Whitworth Equipment's sales staff and, through Armstrong Whitworth/Brush, enquiries for electronic equipment will be channelled to the most suitable of the two parent companies. Both Brush and A.W.E. will continue to operate in their established fields.

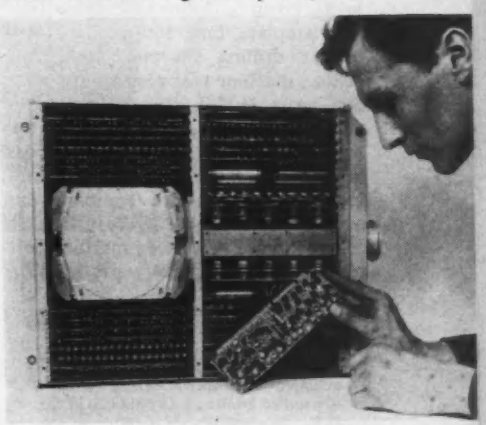
COMPUTATION

Elliott's Verdan computer

Elliott Brothers (London) Ltd have entered into an agreement with the Autonetics Division of North American Aviation Inc., for the sale and manufacture of Autonetics' Verdan ('versatile digital analyser') digital computer. This machine, which basically comprises a general-purpose digital computer, a digital differential analyser or incremental computer, and an input-output section, is unusually compact and designed to be highly reliable. Already extensively used in the guidance and control system of American military aircraft, missiles such as *Hound Dog*, and nuclear submarines—each *Polaris*-carrying nuclear submarine carries three Verdans—this computer does appear to represent a step forward in computer technology. The design itself is understood to have cost over $70m, and the U.S. Air Force placed a further contract worth $35m to study problems of reliability. The result is a versatile computer of high speed, which measures only $15\frac{1}{8}$ in by 8in by $19\frac{9}{16}$in (less than $1\frac{1}{2}$ft³) and weighs 82 pounds.

Verdan employs semiconductors throughout and is built up of 96 plug-in printed-wiring boards. Its memory is a magnetic disk in which the head-to-disk gap is set by an auto-lubricated air bearing.

The d.d.a. section is understood to be capable of processing a problem requiring 128 incremental elements 100 times a second. Operating in parallel with the d.d.a., the general purpose computer performs additional related, or unrelated, computations simultaneously. Aboard *Polaris* submarines it is a major component of the Autonetics inertial navigation system, and



Verdan digital and d.d.a. computer opened to show plug-in modules and (left) the magnetic disk memory

performs all the computation necessary to fix the position of the submarine's missile-launch position.

Elliott's see Verdan's application in this country to much the same sort of thing as in the U.S.A.—as a central computer for weapons systems of various types. However, the advent of the supersonic airliner should provide a civil application. Verdan could be used, together with an inertial or Doppler navigator and a heading reference, to provide demand signals to an automatic flight control system. The machine costs £30,000.

MACHINES

Ferranti's machine-control sales

An increase in the sales of their machine-tool control systems and inspection machines has been announced

by Ferranti. During the past six months, order to the value of £350,000 have been received, 50% of the equipment sold going to the U.S.A. The American interest is believed to result from Ferranti's agreement with the Bendix Corp. for the sale and service in the U.S.A. of Ferranti transistor-hydraulic continuous-path machine-tool controls, numerical positional-control equipment and inspection machines.

Machine-tool economics

E.M.I. Electronics have compiled comparative figures showing the economies obtained using their Emicon machine-tool control system. Two jobs were studied, the drilling of printed-wiring boards with an E.M.I.-Grimston drill, and the drilling of Wiederman press templates on an E.M.I.-controlled Atlantic table.

The costs of jig-drilling one board of a 100-board batch on the Grimston, break down as follows: making drilling template, time 160 min, cost 480 pence; drilling 9·6 min, cost 16·32 pence; machine cost plus interest over five years (£234), 0·9 pence; maintenance etc., 0·82 pence. The cost per board thus totalled 18·04 pence. Under tape control, the costs were: programming 26 min, 52 pence (compare with template cost of 480 pence); loading etc., 1·7 min, 2·45 pence; machine cost plus interest over five years (£2600), 7·49 pence; maintenance etc., 1·69 pence. The cost per board under auto-control, therefore, totalled 11·63 pence.

The manual drilling of single templates on the Atlantic comprised: drilling, reaming etc. 100 holes, 700 min, 2100 pence; capital cost etc. (£234) 66 pence; so that the cost per template was 2166 pence. Under tape control the costs were: programming, 60 min, 120 pence; drilling, reaming etc., 100 min, 300 pence; machine setting, 45 min, 135 pence; capital cost etc. (£7800), 452 pence; the total cost under auto-control being 1007 pence.

NEWS BRIEFS

Shockley four-layer diode, a self-actuated high-speed silicon switch, is handled by Brush Crystal Co. in the U.K. This follows as a result of the acquisition of Shockley Transistor by the Clevite Corp., Brush Crystal's American associate.

Holzer timing switches, clockwork and motor-driven, are to be manufactured and sold in this country by N.S.F. Ltd, following an agreement with W. Holzer & Co., Meersburg, W. Germany.

G. A. Platon Ltd (flow controllers etc.) has removed to 281 Davidson Road, Croydon, Surrey; telephone, Addiscombe 1168.

RANK OUTSIDER A complete mobile closed-circuit television service is now available from a Rank Precision Industries' vehicle, the interior of which is illustrated. The service is based upon the Dage range of television cameras and control equipment now being marketed outside the U.S.A. by Rank's G.B. Kalee Division

MEDICINE

Heart monitoring at Hammersmith

Believed to be the world's best-equipped cardiac centre, the Department of Surgery at Hammersmith Hospital now has central monitoring equipment by New Electronic Products, as well as that company's heart-lung and hypothermia equipment. A central monitoring desk, illustrated, in a separate recording room serves two operating theatres and a recovery ward, although essential measurements are repeated on large meters and oscilloscopes in the theatres.

The middle of the desk contains two twin-channel oscilloscopes, allowing four wave-forms to be viewed simultaneously, and each amplifier channel has an indicating meter. Permanent records are made on a six-channel photographic recorder. There are eight amplifier channels, any six of which may be used to link the recorder with any of the rooms of the cardiac centre.

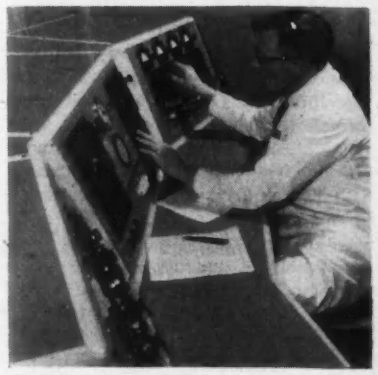
Amplifiers, electrodes and transducers handle electrocardiograms, phonocardiograms, inter-cardiac pressures, electroencephalograms, external-cuff blood pressures, pulse wave-forms and blood pH. In due course a Honeywell multi-point strip chart recorder will be installed for measuring and recording blood, air and surface temperatures.

A dye assembly can also be included in the desk with connexions to the Norman-N.E.P. dye earpiece or cuvette on the patient in the investigation room. A strip chart recorder is also used here.

Working in conjunction with the pressure amplifiers are mean-pressure indicators giving visual indication of inter-cardiac and external-cuff pressures. As the various pressure amplifiers can be switched to the required indicators, there is no need to have an indicator for each pressure. A photographic recorder is used to record most of the physiological phenomena, and this type of recorder can have up to twelve galvanometer channels.

Twin-beam oscilloscopes in the desk show wave-forms of heart movements. Any two wave-forms can be displayed on each 5in screen. In the operating theatre, a large 12in twin-beam oscilloscope is provided so that the e.c.g. and pressure wave-forms can be seen without the oscilloscope being too near the operating table. In other rooms of the centre, 5in oscilloscopes are used. All oscilloscopes are controlled from the desk and any channel being monitored at the desk can be displayed on any oscilloscope.

A tap unit, designed for use with the desk, consists of two still plates lapped together to form a leak-proof seal. The various positions normally required for measuring blood pressures i.e. transducer-to-patient, transducer-to-calibration, and zero and catheter flushing, are obtained automatically by rotating one of these plates electrically. Each tap unit accepts one differential or single pressure head.



The Senior Electronics Technician (Peter Stinton) in the Department of Surgery at Hammersmith Hospital, seated at the central monitoring desk

METALS

Sheet-quality control

A quality control system for the sheet steel and tinplate industries now being produced by the Metal Industries Division of English Electric, is intended for sorting sheared sections of cold strip and rejecting faulty pieces. This 'sheet classifier' stores the information on strip quality obtained during inspection (pin holes, off-gauge, poor finish etc) and uses it when the sheet is cut and ready for sorting into piles. The information is stored and processed by Datapacs, standard transistorized logical elements. A sheet classifier system of any size and com-

The AMPEX CP-100 is a compact, extended-frequency instrumentation tape recorder/reproducer. Tape transport, motor drive amplifier, heads, power converter, controls and all-transistorized plug-in record/reproduce electronics are contained in a single 13¼" x 19" x 33¼" mobile case. The CP-100 operates on 28-volt DC, with 48 to 400 cycle converters available for other power sources. Data is recorded by direct or FM carrier techniques on up to 14 analogue tracks. The CP-100 offers frequency response to 200 Kc at 60 ips or expanded recording time of 24 minutes for 100 Kc data at 30 ips on a standard 10½" reel. Transport tape speeds – 1⅞, 3¾, 7½, 15, 30 and 60 ips – and plug in frequency determining units and equalizers associated with tape speeds, may be quickly changed. The versatile and mobile CP-100 performs reliably over a temperature range of from −50° F to +160° F, up to an altitude of 10,000 feet, in relative humidities to 95%... and is designed to withstand shocks and vibrations encountered in rugged mobile testing applications. This recorder may also be rack mounted if desired. For complete details write Ampex Great Britain Limited, Arkwright Road, Reading, Berkshire, England. AMPEX

COLD-ROLLER AUTO-GAUGED The four-stand four-high tandem cold-rolling mill now in operation at Steel Peech and Tozer's new £2m Brinsworth works, incorporates automatic gauge control. Raw material for cold rolling is supplied from an adjacent hot-strip mill and, after pickling, is delivered to the cold mill in coil form. The tandem mill illustrated is by Davy & United Engineering, and numbers 1 and 4 stands are equipped with automatic gauge control, there being automatic inter-stand tension control between stands 3 and 4. Steplessly-variable inter-stand tension holds the strip centrally within the mill, and any deviation in strip-straightness is indicated at each stand. English Electric electrical plant is used, the mill motors having a combined power of some 4300 hp. These are supplied from rectifier/inverter units which serve the dual purpose of powering the motors during rolling and returning power to the supply during deceleration of the mill. After rolling on the tandem mill, the strip is annealed and transferred to a two-high temper mill (Sir James Farmer Norton) before slitting to size.

plexity can be built for a line of any speed and with a cut-length ratio of as much as 10/1, with these Datapacs. The first units will be installed on number 5 cut-up line at the Abbey Works of the Steel Company of Wales, on two cut-up lines at Richard Thomas & Baldwins, Ebbw Vale, and in a South African steelworks.

The unit at the Abbey Works will be on a steel line operating at 700 ft/min, with cut lengths ranging from 40in to 180in. Sorting will be into rejects and prime sheets. On the two tinplate lines at Ebbw Vale, both of which operate at 1000 ft/min and with cut lengths ranging from 18in to 42in, sorting will be into four piles: sheets with pinholes; off-gauge material; other rejects; prime sheets.

ERGONOMICS

Control room design

The Scottish Centre of the I.E.E. in association with the U.K.A.E.A., Dounreay, organized a Symposium on the Instrumentation and Control of Nuclear Reactors over the weekend 25–26 March. The Meetings, which took place in premises loaned by the Royal Technical College, Glasgow, were by any standard a considerable success. About 120 attended, with particularly strong contingents from Dounreay, Chapelcross and Hunterston.

Eleven papers were presented, but perhaps the most interesting to the control engineer was *The human factor in control room design*, by H. D. Howse. The author adopted the systems approach—that is, there is a job to be done which must be accomplished within certain constraints by some combination of men and machines. He considered particularly the longer-term recommendations relating to the design of the control system of some future nuclear power station. His aims were: safety, for both the general public and the operating staff; and efficiency, or operation at the minimum cost, by minimizing unnecessary trips, maximizing electrical power outputs, and by maximizing the life of the equipment.

He suggested that man's primary function in this system would seem to be in: decision-making, especially in those cases where rule-of-thumb cannot be applied; early entry into the system when a deviation condition begins, so as to arrest a deteriorating situation; and in managing the system so as to optimize the system's aims of safety and efficiency.

On the other hand, Howse, suggested that man should not be used as a primary safety device, a continuous controller (although he must have facilities to allow him to enter control loops in an emergency), or as a monitor—as far as possible monitoring should be automatic.

He then went on to discuss manning, and put forward the proposition that 'one mind in control' was correct; one man must see everything, and all controls should be as accessible as possible. The man must control the system and not the system the man. From this it follows that the control room can be relatively small and compact, but that the man at the desk must have an unrestricted and short-distance view of rear panels. Howse also felt that the operator at the desk may be either seated or standing, but in both cases his eye-height should be constant and the controls and displays the same distance from him. According to the author, when an emergency begins to develop after an uneventful spell, a man's first and almost instinctive reaction is nearly always to stand up. Furthermore, after a long spell of work, changes of posture are necessary for physical comfort and also to dispel boredom.

As for the actual arrangement of the control room, Howse suggested that the desk should incorporate all the moment-to-moment controls and displays, and then went on to discuss schematic panels, alarm systems, deviation instrumentation, information on demand, and information storage, putting forward a number of interesting ideas on how this information can best be presented.

This particular ergonomics study has not been carried out in connexion with a named reactor plant, but it is to be presumed that G.E.C. will be utilizing some of these ideas in the course of time.

NEWS BRIEFS

Educational computers: Redifon have introduced a range of educational analogue computers, based on their Radic system.

Fifth Annual Midlands Instruments and Controls Exhibition will be held at the Central Y.M.C.A., Snow Hill, Birmingham 4, from 25–28 April. Details: A. M. Lock & Co. Ltd, Newborough Road, Shirley, Solihull; telephone, Shirley 5703.

Parvalux (motorized gears, f.h.p. motors, speed controllers, etc.) are now named Parvalux Electric Motors Ltd.

Engineering Laboratory Equipment Ltd (285, Ealing Road, Alperton, Wembley, Middlesex) has been formed jointly by Soil Mechanics Ltd (a member of the Mowlem group) and Griffin & George Ltd, to provide a service in connexion with engineering laboratories.

Denison Loxswitches by R. B. Denison Manufacturing Co., U.S.A., are to be manufactured in this country by Expert Industrial Controls.

Opperman Gears Ltd (gears, geared motors, reduction and worm gears) having export orders to the value of £0·5m, have formed a subsidiary, L.S.A. (Exports) Ltd, to handle exports within the group.

Controlling ballistic missiles

CORRECTION: We apologize for errors in the footnote on p. 102 of last month's issue. These arose from printers' difficulties with the dot notation for time derivatives. We repeat equation (3) below in d/dt notation.

$$C\frac{d^2\theta}{dt^2} = -Tl\sin\zeta \qquad (3)$$

The correction to the caption of Fig. 2 may be clarified by stating that d^2y_z/dt^2 was intended, not dy_z/dt.—EDITOR

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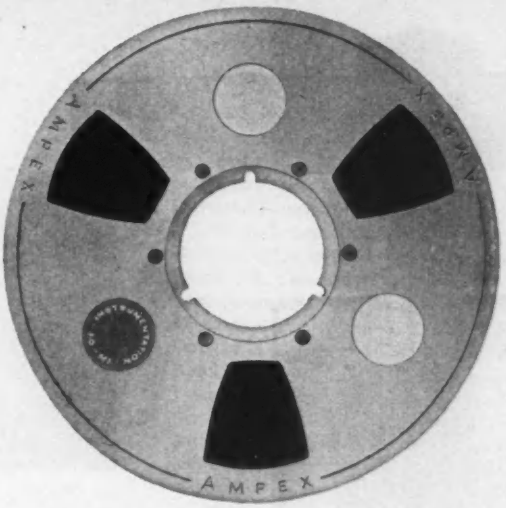

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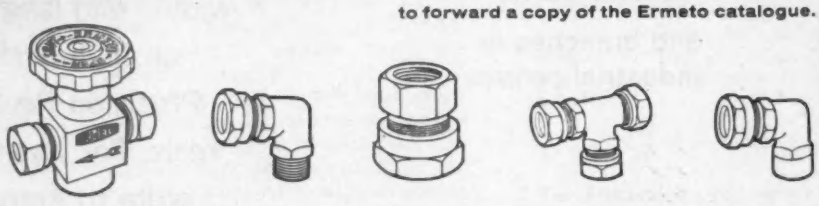

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PEOPLE IN CONTROL

by Staffman

N. McAdam, who has just become Chief Engineer of the Industrial Valves and Cathode Ray Tubes Department of the A.E.I. Radio and Electronic Components Division, is a man of wide experience. He was with Reyrolle, as a student apprentice, a Unit Foreman with Mullard, and joined the (then) Edison Swan Electric Co. in 1935. In 1940 he was placed in charge of Mains Valve Development, became Chief Factory

McADAM
valves

PLEETH
crystals

Engineer in Sunderland in 1947 and Divisional Chief Inspector for the Edison Swan Group of factories in 1955. He joined Copeland and Jenkins as General Manager in 1958 and became a director in 1960.

Turning to A.E.I. (Rugby), I hear that **D. Edmundson**, General Manager, Rugby Works, has been appointed Manufacturing Manager of A.E.I. Electronic Apparatus Division in succession to the late **E. T. W. Barnes**. The new Manager at Rugby Works is **G. P. Thompson**, who was Manager-Manufacturing at Rugby.

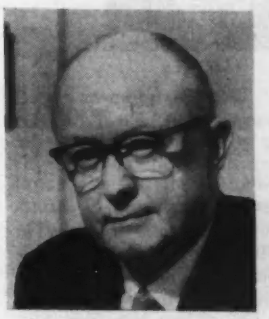
Incidentally, last month the Rectifier Engineering and Semiconductor Engineering Departments of the A.E.I. Heavy Plant Division were merged to form the Power Rectifier Engineering Department. This entailed some reorganization: Dr **J. C. Read** has relinquished the position of Manager, Rectifier Engineering Department, to become Divisional Consultant, Rectifiers; and **W. D. Sinclair**, Manager of the old Semiconductor Engineering Department becomes Manager of the new Power Rectifier Engineering Department.

Well known in electronics circles, **Michael J. Pleeth** has been appointed Marketing Manager of Brush Crystal Co. He joins them from Plessey where he has held several senior positions since leaving the navy in 1947.

The Firth Cleveland Group has become one of those multiple organizations which have so many branches to their family tree that they are difficult to disentangle. I hope that the situation will become clearer now that **Graham Cooke**, a director of Solartron, has been appointed Group Publicity Director. There has been a rash of new appointments within the Group. **Stanley H. Goss** and **L. G. Oxford** have been appointed Joint Managing Directors of Firth Cleveland Instruments. Goss became Assistant Managing Director of Simmonds Aerocessories, in January 1960 and a director of Firth Cleveland Pumps in 1959.

There have been three appointments to the Board of the Solartron Electronic Group recently, **R. Catherall** becomes Director of Research and Development, **H. D. Binyon** Director of Product Sales, and **L. Malec** Director of Systems Sales. Catherall was at Rotol, concerned with propeller vibration, Pametrada, where he started and built up the Electronics Department, Smith's, on automatic pilot design, and joined Solartron Laboratory Instruments in 1952. He was responsible for the design of the Solartron transfer function analyser. In 1957 he was appointed Director of Solartron Research and Development. Binyon was at the Cavendish in 1947, then at Elliott Bros and Muirhead, joining Solartron in 1952. He became Director of Solartron Laboratory Instruments in 1955. Malec has an aviation background. He was with the R.A.F., concerned with synthetic training in British European Airways, was Deputy Managing Director of Air Trainers Ltd, and was appointed Managing Director of Solartron Radar Simulators on 1 January 1959.

I see that **Clifford Metcalfe**, Managing Director of E.M.I. Electronics, is to give up that position on 1 July, and will be succeeded as M.D. by the present Deputy Managing Director, **Percy A. Allaway**.



METCALFE
relinquishing

ALLAWAY
succeeding

Apparently Metcalfe, who will remain a full-time director of Electric & Musical Industries Ltd and concerned mainly with initiating new product policy, wanted to relinquish the job. He started with Bristol Aeroplane on engine design, and joined the Gramophone Co. in 1930 as a mechanical designer. Metcalfe became a director of E.M.I. Engineering Development in 1946, Managing Director in 1954 and E.M.I. Electronics' M.D. in 1956. Allaway has parallelled Metcalfe's career: he also joined the Gramophone Co. in 1930, spent the war years designing radars etc., and

then transferred to E.M.I.'s domestic side for work under Metcalfe. Allaway became General Manager of E.M.I. Engineering Development in 1953, and Works Director in 1956. When Metcalfe formed E.M.I. Electronics, Allaway became Works Director of that company, and Deputy Managing Director in 1957.

Two engineers have been appointed to the Board of the Leigh-on-Sea firm, M.T.E. Control Gear Ltd, **B. L. Bardell** and **N. H. Olley** who become Joint Technical Directors. Bardell was Chief Electrical Engineer, and Olley Chief Design Engineer responsible for the design and development of M.T.E.'s range of control components.

Expert Industrial Controls Ltd, of Ashby-de-la-Zouch, the company formed recently by amalgamating Sharp Control Gear and Electran Coil Co., have promoted their Field Sales Manager, **H. J. Wigner** to be Sales Manager, and their Chief Draughtsman, **E. Mason,** Chief Engineer.

J. Bell, the new Managing Director of the G.E.C. subsidiary, M-O Valve, in succession to **G. A. Marriott** who retired on 1 April, joined G.E.C.'s Wembley laboratories (now the Hirst Research Centre) in 1929. He was responsible for all thermionic valve research work at Wembley, became deputy to the Director in 1951, and an M-O Valve director in April 1960.

AUTHORS IN CONTROL

Gordon A. Jones (*You still have to convince the operator,* page 82) has been with Honeywell Controls for fourteen years. After wartime experience as a Chief Petty Officer in the Electrical Branch of the Royal Navy, he joined Honeywell's Perivale works, where he was in charge of the calibration and testing of electronic recorders and controllers. He has had many years as a 'trouble-shooter', and became head of the Commission Section. Last year he was appointed Manager of the company's Contract Supervision and Installation

JONES

Department. Jones has given many lectures on commissioning and installation problems.

A. P. Roberts (*Self-optimizing control systems,* page 84) graduated in mathematics from Manchester University in July 1951. He became a Scientific Officer in the Guided Weapons Department at the Royal Aircraft Establishment, and was promoted Senior Scientific Officer in January 1957. Since June 1958 he has been Lecturer in the Control Section of the Electrical Engineering Department at the Imperial College of Science and Technology. On 1 October, Roberts will take up the appointment of Senior Lecturer and Head of the Department of Engineering Mathematics at The Queen's University of Belfast.

Thomas B. Wearden (*Selecting small servo-motors,* page 90). See page 111, March 1961.

G. H. Inglis (*Control of blowers,* page 93) graduated in mechanical engineering from King's College, University of Durham, in 1949. He started an apprenticeship with C. A. Parsons & Co. Ltd in 1943, and was subsequently engaged on gas turbine design and development with Parsons, being attached to the National Gas Turbine Establishment, Pyestock, from 1950 to 1952. Inglis was attached to A.E.R.E. Harwell, and the Department of Atomic Energy, Risley, from 1952 to 1955, and engaged on the Calder Hall project. He returned to Parsons on the formation of the Nuclear Power Plant Co. and was appointed Chief Mechanical Engineer in 1956. He was concerned with Bradwell, Latina and Dungeness nuclear power stations, and joined the U.K.A.E.A. Production Group in 1960 as Deputy Chief Engineer (Fuel Elements).

M. G. Hartley (*Versatile analogue computer for g.w. studies,* page 98) graduated in mechanical engineering in the Faculty of Technology at Manchester University in 1953. After a practical training in industry with Simon Handling Engineers Ltd, Stockport, he returned to the Faculty of Technology in 1954 as a research student in the Electrical Engineering Department. He received an M.Sc. Tech. degree in 1956 for work on the secondary-emission properties of cathode-ray tubes. During the years 1956–8, he was a development engineer at Ferranti Ltd, Wythenshawe, Manchester. Hartley is now a lecturer in the Electrical Engineering Department of the Faculty of Technology at Manchester University. His special interest at present is an Isograph machine for the determination of the roots of algebraic equations.

G. B. Marson (co-author with I. C. Hutcheon—below—of *Electronics in industrial process control,* page 102). See page 111, March 1961.

I. C. Hutcheon. See page 111, March 1961

P. F. Blackman (*Pole-zero approach to system analysis,* page 106.) See page 126, November 1960.

S. Handel (*Semiconductor developments,* page 109) was at Regent Street Polytechnic and University College, London. He joined Standard Telephones and Cables, North Woolwich, as a junior

HARTLEY

HANDEL

engineer in 1938, designing components, a.c. bridges and measuring equipment, and carrier equipment. In 1946 he joined E.M.I. Engineering Development as senior engineer in charge of component design for v.h.f. transmitters, mobile radio-telephones, and military and marine radars. Since 1955 he has been an independent consultant specializing in semiconductor devices and electronic techniques in industry.

N. G. Meadows (*Determination of time constants from a transient response,* page 115) studied part-time at Bristol College of Technology while employed by the Admiralty as a design draughtsman on fire-control projects. A full-time course in technical teaching at Garnett College followed, qualifying him for a lectureship in power engineering at Twickenham Technical College from 1952 to 1955. He then entered industry as a patents engineer, and carried out technical liaison between the head office and works of Redifon, being concerned with flight simulators and electronic controls. Leaving Redifon in 1956, Meadows took up his present post at Wimbledon Technical College, where he has been largely responsible for the initiation and organization of courses for N.H.C. students and graduates in control systems and analogue computers. He is also visiting lecturer in control systems at Crawley College of Further Education.

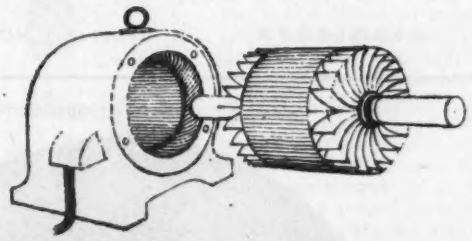
Electrical Aids in Industry — *Data Sheet* **No. 14**

Electric Motors & Controls 1

Most manufacturers today employ electric motive power through individual drives, which, among their many advantages, permit the right type of motor to be used for each of various types of machine. The range of motors available—each with its own characteristics—is very large, and the factory executive could well be guided in his choice by the expert views of the motor manufacturer, the installing engineer or his Electricity Board's engineer. The characteristics of the main types of motor are briefly summarised below.

Squirrel-cage Motors

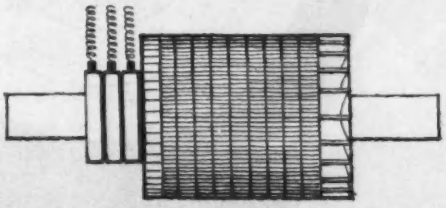
These are the most straightforward and simple in design, and are therefore relatively cheap and robust in character. They should be considered for general duties and, in conjunction with variable-speed gears or couplings, for applications requiring variable speeds, e.g. for crane drives. Small sizes can be switched direct-on-line.



The squirrel-cage motor is very suitable for individual drive of each motion of single-purpose machine tools where the motor horsepower can be precisely specified. It is suitable for driving pumps, fans, lifting hoists and woodworking machines. Textile machinery represents another field of use.

Slip-ring Motors

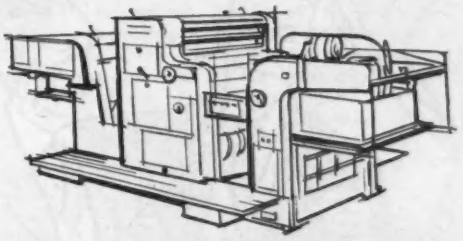
The chief advantage of the slip-ring motor is a very low starting current for a given torque, e.g. full-load torque at starting with a current about 10% above full-load current. This makes it suitable for applications requiring a prolonged starting period with a



load of high inertia. It also permits of speed variation below synchronous speed, though with some loss of efficiency. Typical applications include fans, pumps, heavy lathes, grinders and boring mills, as well as calendering machines, cable-laying-up machines and mine hoists.

Three-phase A.C. Commutator Motors

The main characteristic of this type is variable-speed with uniform and gradual acceleration and good efficiency over the speed range. Paper manufacture provides excellent examples of its use, e.g. in paper-making, reeling, cutting, calendering, coating and drying.



A.C. commutator motors are recommended for mechanised bakeries and for cranes and hoists where very slow speeds are frequently needed.

Synchronous Motors

These are constant-speed motors. One particular advantage is that they can be operated at unity or even at leading power factor to correct a system suffering from lagging power factor, and perhaps so qualify for a reduction in the electricity bill. Pump and compressor drives are typical uses to which they can be put. They are also used in motor-generator sets.

Single-phase A.C. Motors

In general, single-phase motors are used in light industries for drives not requiring more than about five horsepower or where a three-phase supply is not available. While their use is mainly limited to work of a light nature, they do fill a need in such duties as sewing-machine drives, portable hand tools, window opening and closing gear, etc.

Direct Current Motors

For a completely unfettered performance where wide ranges of speed variation, high rates of acceleration and powerful dynamic braking are all-important, the D.C. motor is unrivalled. This means in effect the installation of an A.C.-D.C. motor-generator set or rectifier to give the necessary supply, but the increased cost may well be compensated by the improvement in productivity. When variable voltage is applied to the armature, a wider speed range is obtainable than with any other type of motor. Typical applications of the D.C. motor are: cranes, haulage and tippler equipment, certain machine tools requiring a large speed range and smooth acceleration, high-speed printing and steelworks drives.

For further information, get in touch with your Electricity Board or write direct to the Electrical Development Association, 2 Savoy Hill, London, W.C.2. TEMple Bar 9434.

They can offer you excellent reference books on electricity and productivity (8/6, or 9/- post free)—"Electric Motors and Controls" is an example.

E.D.A. also have available on free loan within the United Kingdom a series of films on the industrial uses of electricity. Ask for a catalogue.

7914

Circle **No 84** on reply card for further details

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Inexpensive stock equipment made under the registered trade names of "COUNTEC", "REGISTEC" and "PHASITRON" provide the facility to construct a number of simple control systems using Photo Electric and electronic timing techniques for all kinds of purposes—send for details.
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ECONOMICAL

Temperature Control

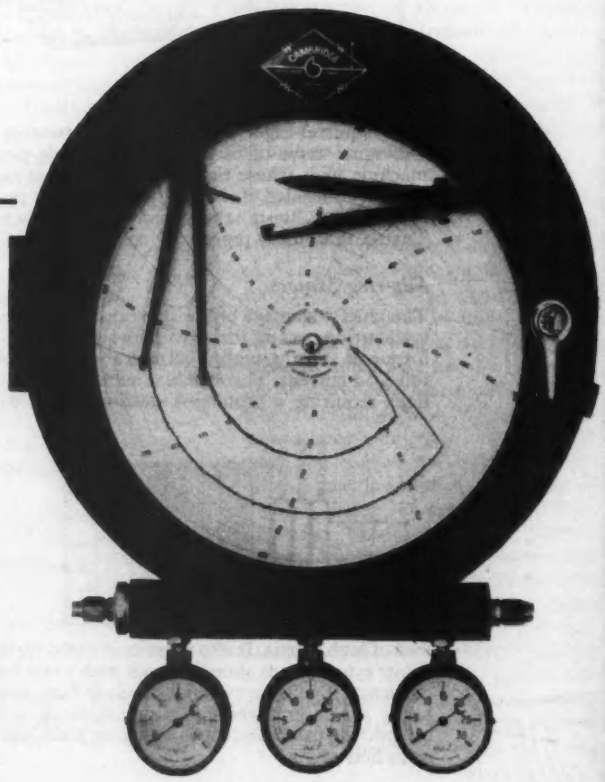
The Cambridge high standards of accuracy and reliability are available in this recording controller and the price is thoroughly competitive. Temperatures between *minus* 75°C and *plus* 600°C (*minus* 100°F and *plus* 1,100°F) are covered, using either a mercury-in-steel or a gas-filled system. It is made in three main forms—for electrical, pneumatic or hydrostatic operation, the latter two being suitable where flame-proof restrictions apply.

The controller is single or double (as illustrated) and one system of the latter can also be used to control pressure. Alternatively, the instrument can be arranged to give programme control, and provision is made for the operation of visual or audible alarms, timers or other mechanical devices.

Charts (10 inches diameter) are available for 12 hrs, 24 hrs, 7 days or other durations.

SEND FOR LIST CD 334

For future publications, ask for mailing form CD/4/61



Cambridge **THERMOGRAPH CONTROLLERS**

CAMBRIDGE INSTRUMENT COMPANY LTD
13 Grosvenor Place, London, S.W.1

New for Control

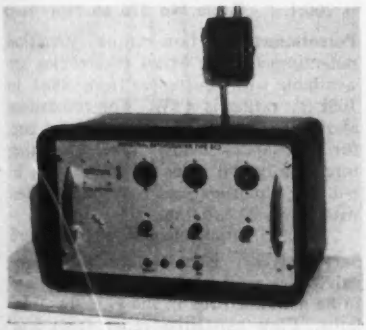
A product review for the control and instrument engineer

For further information, circle the appropriate number on the reply card facing page 162.

BATCH COUNTER

rapid and easy modification

Units made by the Electronic Machine Co. have been re-designed to give a flexible form of basic instrument. Use of comprehensive printed circuitry allows the basic instrument to be taken from



Flexible

stock and the necessary components to meet a specific requirement to be added in only a few minutes.

Counting speed is up to 20,000 per minute and the circuit is easily modified to cater for dual inputs, magnetic pick-up inputs, photocells etc. The unit is made for rack, panel, or case mounting to standard G.P.O. sizes.

Circle **No 520** on reply card

TONE-TELEMETRY EQUIPMENT

thirty channels

Transistorized tone-telemetry equipment by Elliott is intended for the frequency division multiplexing of tones in the band 300–3000 c/s over a single telephone or radio link. Thirty channels of information may be transmitted simultaneously; five of these may be used for control purposes, the control signal being a 50-c/s modulation superimposed on the carrier tone.

The system is built up from standard plug-in units mounted on 19-in panels. Tone generators and receivers, mixer and receiver amplifiers, and ancillary equipment such as power packs, can be assembled to form out-stations or control stations as necessary. The system works from a 24-V d.c. supply, and a sealed battery-unit will give two hours' operation in the event of a mains failure.

Circle **No 519** on reply card

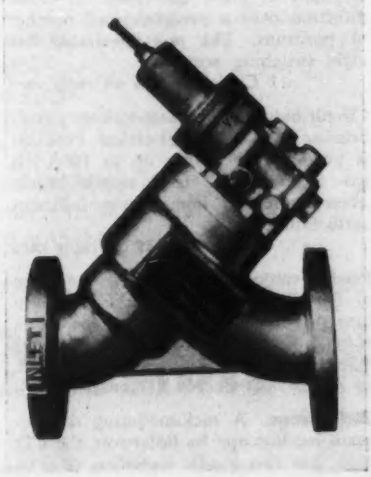
CONTROL VALVES

linear characteristics

The Brodie 500 series range of control valves is now marketed in the U.K. by Gilbarco. The valves may be actuated by single or multiple pilots operated electrically, pneumatically, or hydraulically. For electrical operation, solenoids can be supplied for most standard voltages (110V, 230V, etc.); for hydraulic or pneumatic operation the control pressure will in general be dependent upon product-line pressure. It is claimed that a single valve with multiple pilots will control flow and pressure and act as an on-off remote control and check valve.

Sizes available are 2 in to 12 in, all valves operating at up to 600 lbf/in² at ambient temperatures up to 150°F.

Multifarious



Although developed primarily for the petroleum industry, these valves will handle any compatible fluid.

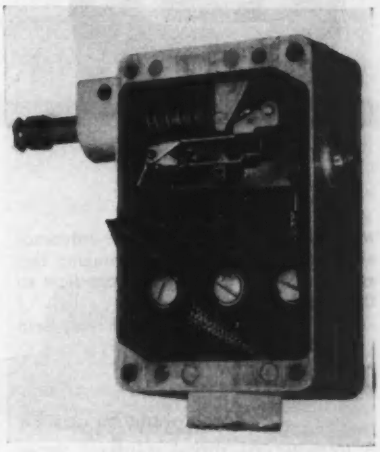
Circle **No 522** on reply card

PULSE SWITCH

mechanically operated

Honeywell's I.P.D.I. switch is intended for applications where momentary opening or closing of a circuit is necessary. When the plunger is depressed, the contacts are closed during a definite predetermined length of travel of the actuating rod, adjustable from 0·03 to 0·45 in. The pulse-length is therefore determined by the speed of depression of the plunger.

The switch is single-pole double-throw, and is rated at 10A at 480V for a.c., and 0·5A at 125V or 0·25A at 250V



Impervious

for d.c. The unit is impervious to oil, water, and dust, and life expectancy is 5 million operations.

Circle **No 530** on reply card

HIGH-PRESSURE PUMP

output up to 4000 lbf/in²

Available from Dowty is the Vardel piston-pump for industrial applications which gives hydraulic pressures up to 4000 lbf/in². Output at 1500 rev/min is 2·4 gal/min, the output being directly proportional to speed up to 3000 rev/min. Incorporated is a control mechanism which reduces output flow to zero at a predetermined pressure and gives a high holding pressure at low power input without fluid overheating. A fixed-delivery version of this pump is also available. Circle **No 523** on reply card

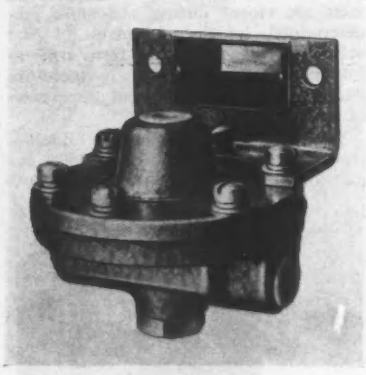
LOW-FLOW CONTROLLERS

gas or liquid

Available from A.E.I.'s Instrumentation Division is a range of controllers which automatically regulate flows as low as 1–47 cm³/min (s.t.p.) of gas, or 0·18 cm³/min of liquid. There are two versions: one maintains a constant gas or liquid flow through any external needle-valve

irrespective of variations in downstream pressure; the other is for use when downstream pressure is constant. Either version may be made in brass or stainless steel: brass models may be used at pressures up to 250 lbf/in² and temperatures up to 180°F; stainless steel models are rated to 500 lbf/in² and 250°F, or 390°F with reduced life.

These controllers use feedback from the supply or downstream flow line to



Automatic

maintain a constant pressure-difference across a spring-loaded diaphragm: this regulates a valve plunger, hence flow to the needle valve.

Circle **No 533** on reply card

DIGITAL VOLTMETER

high input-impedance

A transistorized digital voltmeter (series 5000) made by Electronic Associates has a high input-impedance which does not depend upon a null condition within the instrument (i.e., does not change during measurement). An average of 200 readings per second may be achieved with an accuracy claimed to be ±0·01% with respect to either an external reference, or to the internal zener reference which itself has an absolute accuracy better than 0·01%. Three ranges cover 0 to 999·9V as follows: 0–9·999 V (input impedance 1000 MΩ); 0–99·99 V (input impedance 1 MΩ); 0–999·9 V (input impedance 10 MΩ).

An in-line in-plane projection system is used to display the four digits, decimal point, and automatically indicated polarity. Dimensions of the unit are 19½ × 6½ × 17½ in. Circle **No 528** on reply card

PROXIMITY SWITCH

inductive principle

A unit by Donovan Electrical operates by inductive coupling, the detector head being completely sealed. A substantially flat metal surface, say 1 or 2 in² in area, coming within about ¼ in of the face of the head causes the relay to operate. (The relay is normally fitted with two changeover contacts rated 5A at 250V). Provided that a sufficient flat surface is presented to the head, any type or thickness of metal will be detected, but swarf and metal dust will normally have no effect due to their small particle size. The switch will operate up to five times per second when using the internal relay, but faster operation may be obtained by using external static-switching equipment.

The normal head is 1½ in diameter, and this is coupled by 6 ft of coaxial cable to the control unit, which measures 7 × 6 × 4½ in. Nominal value of mains supply is 230 or 400V a.c., but wide variations are permissible. Power consumption is about 6W.

Circle **No 524** on reply card

PISTON VALVES

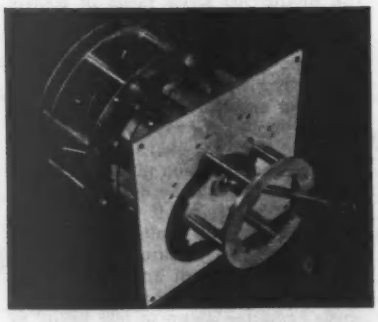
electric or pneumatic operation

A range of ¼-in B.S.P. valves is available from Martonair for manual, electrical, or pneumatic operation. Operating pressure range (liquids) is 30–100 lbf/in², and the valves will handle 180 ft³/min at 80 lbf/in²; operating movement is ⅛ in. Designated S.700, the valves are made from a high-tensile light alloy, and will carry most normal fluids.

Circle **No 525** on reply card

QUICK LOOKS

Selector switch. Made by Pye for furnace control, the lever of this joystick switch may be moved clockwise to select



different furnace temperatures. A mechanical interlock prevents anti-clockwise movement, but the interlock can be arranged to allow movement in either direction over a predetermined number of positions. The unit illustrated has eight switching positions.

Circle **No 535** on reply card

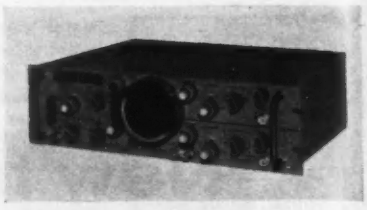
Circuit breaker. An earth-leakage circuit breaker by Chilton Electrical Products is available in ratings up to 100A. It has a prominent 'test' switch which, when depressed, immediately indicates earth faults.

Circle **No 539** on reply card

Plastics valves. An addition to the range of Barflo all-plastics valves is the flap-type non-return valve. It can be made from most rigid plastics, the 'flapper' being made from Neoprene rubber.

Circle **No 517** on reply card

Oscilloscope. A rack-mounting double-beam oscilloscope by Solartron, the CD 1016, has two *Y*-axis amplifiers (d.c. to 5Mc/s). Nine calibrated sensitivity ranges (accuracy ± 5%) cover 100mV/cm to 50V/cm. Time base range is 1cm/μs to 2cm/s. Input impedance is



1MΩ and 30μμF, and inputs may 'float' up to ± 500V relative to chassis for displaying signals isolated from earth. Circle **No 518** on reply card

Batch counters, with 2, 3, 4, or 5 Dekatron tubes, are available from Pentechnique. They will count up to a total of 99,999, at counting rates up to 5000 per second. Input may be from photoelectric or magnetic pick-ups.

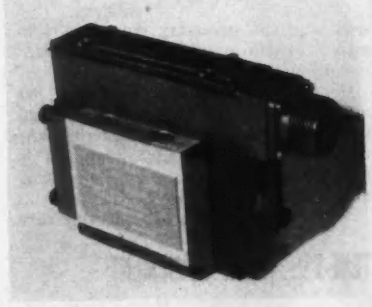
Circle **No 515** on reply card

Grid-controlled rectifier. The Ediswan 21B12 xenon-filled grid-controlled rectifier has a heating-time of about 30 s. Maximum peak forward and reverse anode voltages are 1·0kV and 1·25kV respectively, and maximum mean cathode current is 2·5A. Control ratio is 200:1. Circle **No 516** on reply card

Potentiometers. Low-torque precision potentiometers by Miles Electronics are available with resistances from 500Ω to 100kΩ; rating is 4·5W. For resistances above 10kΩ, starting torque is 5gf cm; for resistances below 10kΩ, starting torque is 7gf cm. The MCD 20 is 2⅝ in o.d. by 1 in deep, and may be supplied with up to 33 tappings.

Circle **No 536** on reply card

Servo-valves. Electrohydraulic servo-valves designed by Pegasus (U.S.A.) are to be manufactured in the U.K. by Telehoist. Flow capacities range from 5 to



60 gal/min, at pressures up to 3000 lbf/in². These valves are intended for use where weight is an important factor, the largest weighing only fifteen ounces.

Circle **No 538** on reply card

Resistance bridge. Startronic's low-resistance measuring bridge, model 100, measures resistance from 0·05Ω to 50kΩ in five ranges. The calibrated dial is 4 in diameter, and the null indicator is a moving-coil mirror-scale meter. Two

NPN DIFFUSED JUNCTION

SILICON POWER TRANSISTORS

2 TO 30 WATTS DISSIPATION AT 100°C

OUTSTANDING FEATURES

- ★ Extremely low saturation resistance
- ★ High current and power dissipation ratings
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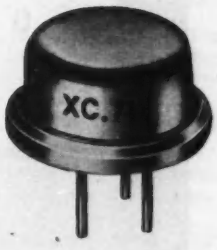
LOW POWER TYPES



MEDIUM POWER TYPES

HIGH POWER TYPES

		XC703	XC713	XC723
Maximum collector/base voltage (volts)		60	60	60
Maximum emitter/base voltage (volts)		12	12	10
Minimum h_{fe}	(V_{ce} = 4V, I_c = 200 mA)	15	—	—
	(V_{ce} = 4V, I_c = 750 mA)	—	15	—
	(V_{ce} = 4V, I_c = 1.5 A)	—	—	10
Average f_α	(V_{cb} = 28V, I_c = 5 mA) (Mc/s)	1.5	—	—
	(V_{cb} = 28V, I_c = 5 mA) (Mc/s)	—	1.25	—
	(V_{cb} = 12V, I_c = 100 mA) (Mc/s)	—	—	1

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TA15/87

Circle **No 86** on reply card for further details

NOW Servo Power in New Taylor TRANSCOPE Transmitter

A high-accuracy, low-cost, motion-balance pressure transmitter

Taylor's new integrated line of pneumatic transmitters features servo-driven indication as an option on the indicating model. This provides ample power for process alarms — and other auxiliary functions such as digital encoders and potentiometers — with no loss of accuracy in the transmitted signal. Not only does it satisfy today's requirements . . . it provides for possible future needs. Other important features of the TRANSCOPE **210T** include:

* **High accuracy.** Transmitted signal is within ½% of the input signal. Indication is within ± 1% of actual value.

* **Exceptional readability.** Big 11¾" long concentric 270° scale can be read easily at 25-35 ft. Yet case measures only 7" x 9" x 4".

* **Threshold sensitivity.** 0·1% of input span. Low-friction drive mechanism permits accurate handling of low-energy input signals.

* **Designed for easy maintenance.** Only 3 basic parts. A high quality encapsulated motion amplifier; single-packaged pneumatics . . . servo-powered follow-up and relay valve; interchangeable, time-tested actuating elements.

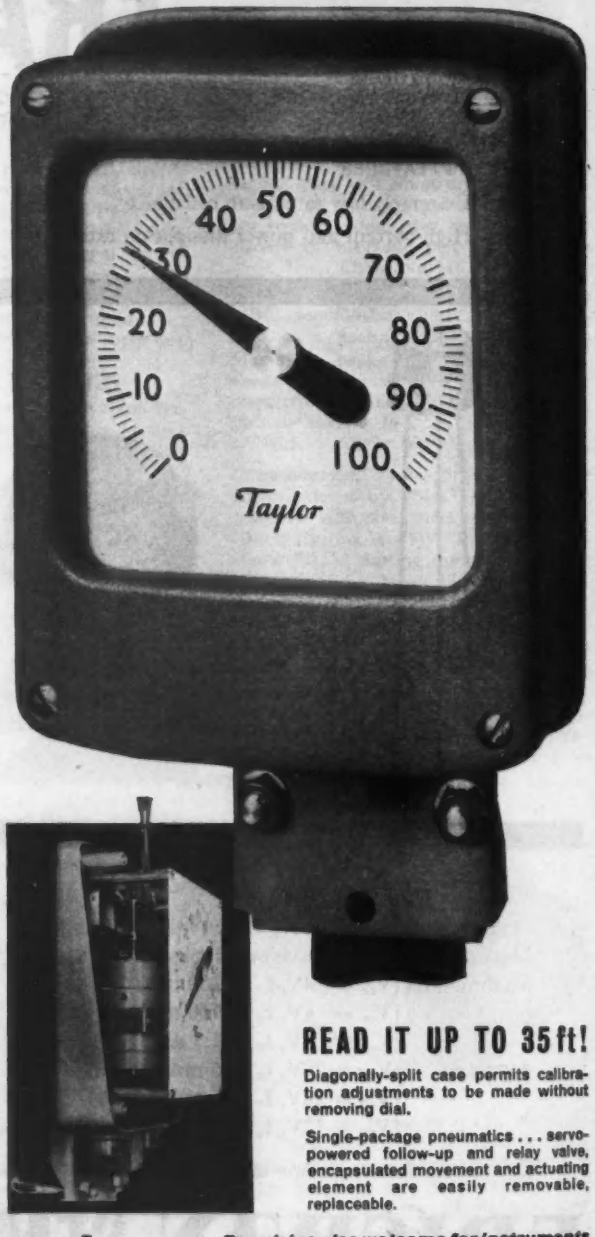
* **Lower inventories.** Benefits large users of instruments by utilizing actuating elements which are common with FULSCOPE and other Taylor indicating, recording and controlling instruments.

* **Conveniently calibrated.** Diagonally-split case makes all adjustments easily accessible by merely removing cover.

* **Weatherproof case.** Hammered grey enamelled finish on die-cast aluminium case . . . designed for field installation.

* **Adaptable mounting.** Universal bracket permits wall or pipe installation.

* **Non-indicating model (211T)** has same performance as 210T except for process indication.



READ IT UP TO 35 ft!

Diagonally-split case permits calibration adjustments to be made without removing dial.

Single-package pneumatics . . . servo-powered follow-up and relay valve, encapsulated movement and actuating element are easily removable, replaceable.

For full details of this new transmitter please contact:

Taylor Controls Limited

Enquiries also welcome for instruments for measuring volumetric pressure, volumetric load and temperature, which will be available later.

Hale End Road, Walthamstow, London, E.17. Telephone: Larkswood 5533. *A subsidiary of the Taylor Instrument Companies, Rochester, N.Y., U.S.A.*

INSTRUMENTS OF THE FUTURE WILL HAVE SERVO-POWER—TAYLOR HAS IT NOW!

further models are the 108, covering 0–0·16 Ω in a single range accurate to ± 0·001Ω or ± 2% depending on the part of the scale in use, and model 110, which is a comparison bridge directly calibrated ± 10%.

Circle **No 534** on reply card

Universal solder. A fluxless solder made by Industrial Synthetics (Overseas) Ltd will work effectively on aluminium and its alloys as well as standard metals. An ordinary iron may be used, as the solder will take at about 210°C.

Circle **No 540** on reply card

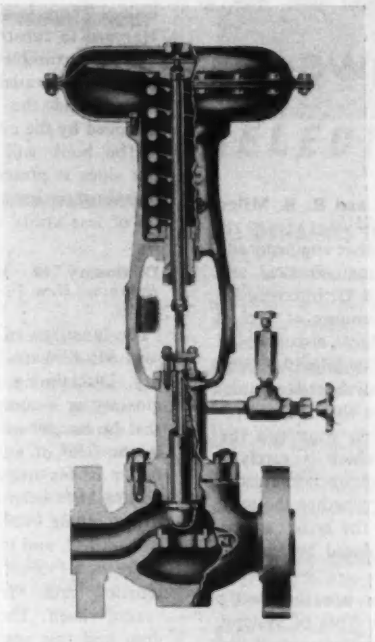
Air-line lubricators. Martonair's lubricators are claimed to provide a constant proportion of oil mist over wide air-flow ranges. At a pressure of 80 lbf/in², the ML2 (¼-in B.S.P. ports) will handle 2–30 ft³/min and the ML3 (½-in B.S.P. ports) 2–100 ft³/min.

Circle **No 526** on reply card

Digit selector-switch. A wafer-thin switch, which can be mounted on edge, is available from Armstrong Whitworth Equipment. It has ten positions, the contact segments being etched copper foil, rhodium-plated, or Bakelite laminate. These switches may be installed in rows in any number of banks, position numbers on the front edge giving in-line indication of switch positions.

Circle **No 527** on reply card

Control valve. The Masoneilan 20,000-series heavy-duty single-seat control valve is available from Crosby Valve, screwed ¼ in to 2 in, with trim sizes from ½ in. to 2 in. Heavy top-guiding of the



plug is claimed to eliminate the need for orthodox bottom-guiding, so reducing turbulent flow.

Circle **No 537** on reply card

Encoding system. The BEL-5 angle encoding system, developed by United Aircraft's Norden Division (U.S.A.), is available in the U.K. from Ketay. The system divides a single shaft-revolution into 360,000 parts, and provides parallel real-time outputs in three forms: electrical 8–4–2–1 binary-coded decimal; electrical straight decimal; visual decimal on neon tubes. Total weight is 140 pounds, and power requirement is about 650W.

Circle **No 531** on reply card

Thermocouple wires. The range of Thermocoax miniature thermocouple wires has been extended by two smaller sizes with outside diameters of 0·34 mm and 0·25 mm respectively. They are available from Research and Control Instruments in limited continuous lengths up to 6m, in stainless steel sheaths.

Circle **No 532** on reply card

Miniature relays. Very small relays by Guardian Electric (U.S.A.) have standard contact ratings of 3A at 125°C. They will switch currents down to 10 μA at 30 mV.

Circle **No 521** on reply card

Power supply. A transistorized power supply by Invar (U.S.A.) gives an output of 0–36V d.c. at 30A. Line regulation is 10mV max., load regulation is 5mV max., and ripple is 1·0mV max. The TP–30 is 7 in high by 20 in deep, and will mount in a standard 19-in rack.

Circle **No 529** on reply card

ERRATUM

Linear measurement: we regret an error in the accuracy quoted in last month's issue for the Reilly Engineering displacement transducer (p. 137). The accuracy claimed by the makers for a 1-in displacement is ± 0·00003 in, not ± 0·0003 in as stated.—EDITOR.

PUBLICATIONS RECEIVED

An automatic 1000 channel read-out system *by* R. L. Elliott. A.E.R. Harwell. 1960. 26 pp. 4s. 6d. ★ 548

A device for the synchronisation of two dropping mercury electrodes *by* W. H. Lockwood. A.E.R.E. Harwell. 1960. 7 pp. 1s. 9d. ★ 549

Adaptive control systems. *Edited by* Eli Mishkin and Ludwig Braun, Jr. McGraw Hill Publishing Co. Ltd. 1961. 533 pp. £6 8s. ★ 550

Gas gain drift in a gas flow X-ray proportional counter; a method of stabilisation *by* C. E. Mellish and J. A. Payne. A.E.R.E. Harwell. 1960. 9 pp. ★ 551

The Engineer Buyers Guide 1961. Morgan Brothers (Publishers) Ltd. 984 pp. 10s. ★ 552

Gear unit. A light duty gear-unit for use with certain of their wrench-operated valves is described in publication 609 from Audco. ★ 553

Miniature time-indicators are the subject of a leaflet from Haydon (U.S.A.). ★ 554

Semiconductors. G.E.C.'s Semiconductor Device Guide, January 1961, contains brief specifications of their entire range. ★ 555

Gyro compass. An illustrated booklet from Sperry gives details of their Mark XX compass. ★ 556

Silicone compound MS4 by Midland Silicones is the subject of publication reference C6 Ed.4. ★ 557

Recorders by Everett Edgcumbe are described in their illustrated catalogue No 301. ★ 558

Etched-wiring circuits are the subject of a leaflet from Printed Circuits Ltd. ★ 559

Telecommunication measurement equipment is described in detail in a 171-page catalogue from Marconi Instruments. ★ 560

Nuclear health. A short catalogue from E.M.I. gives details of radiation monitors designed for personnel protection. ★ 561

Power supplies. Catalogue No 401 from Invar Electronics (U.S.A.) gives complete specifications of their range of transistorized power supplies. ★ 562

Tin research. The 1960 annual report of The Tin Research Institute gives details of research and development in the U.K. and overseas. ★ 563

'Dry pneumatics' is the title of a booklet from Birlec describing their adsorption driers. ★ 564

Resistance welding. Materials for electrodes made by Johnson, Matthey are fully described in their leaflet, No 7200/3. ★ 565

Annual report of Texas Instruments (U.S.A.) contains the financial statement for 1960 and details of current activity. ★ 566

Resistors for steelworks duty are listed in publication No FP121 from Fawcett Preston. ★ 567

Bin controller. The Leveltron multi-point automatic controller is described in a leaflet from Thomas Industrial Automation. ★ 568

Pivoted disk valve. The Winn Flexiseat valve is the subject of folder WF1 from the B.W. Valve Co. ★ 569

Electric furnaces for all industries by Metalectric are illustrated in their bulletin No M.1. ★ 570

★ Circle the relevant number on the reply card facing page 162 for further information

Book Reviews

Servo-mechanisms

Principles of Servomechanisms *by* **A. Tyers and R. B. Miles.** *Sir Isaac Pitman & Sons Ltd. 1960. 176 pp. £1 5s.*

This book is addressed to junior and maintenance engineers and would-be servo-mechanics students with a mathematical and electrical theoretical background at about C. & G. Intermediate or O.N.C. level. The book begins with accounts of typical systems, together with a qualitative and graphical discussion of transient response, including the effects of acceleration and rate feedback. Unfortunately the authors have erred on the side of over-simplification to such an extent that quite erroneous impressions could be conveyed; e.g. on page two the authors refer to open-loop servo-systems, which is surely a contradiction in terms, and to closed-loop servo-mechanisms, which is tautological. At times it is not clear whether the term 'input' refers to the command signal or to the error, as e.g. on page six, line 27, where, if 'input' is replaced by 'error', the correct sense is conveyed.

Many of the transient response diagrams are incorrectly drawn, e.g. Figs. 1.6; 1.8; 2.2; 2.3 etc. In the types of systems referred to, on applying a step input the initial velocity of the output must be zero, as accelerating torques are finite, so that error and output curves should start with zero gradient at the origin. This is particularly important in Fig. 2.2 where a derivative curve is plotted, unless this is intended to apply to an arbitrary time value. Damping and velocity feedback are considered as separate entities, and the discussion here begs the whole question: it is difficult, for example, to see the relevance of Fig. 2.3. Several other errors of fact occur: in the section on error detectors, pick-offs generally are referred to as error detectors. In Fig. 3.9 the motor field is omitted.

The chapters on synchro elements, magnetic amplifiers and modulators are useful and instructive, and that on analogue computing also, although the integrator, perhaps the most important part of an analogue computer as such, is omitted.

This book could profitably be read by a newcomer to the field, particularly the later chapters, but the inconsistencies in the early part of the book might well deter the more critical reader.

N. G. MEADOWS

Translation

Automatic Language Translation *by* **A. G. Oettinger.** *Harvard University Press, London: Oxford University Press. 1960. 380 pp. £4*

The main contribution of this book to the problem of machine translation is its detailed description of the methods of dictionary search which are most appropriate when the dictionary is stored on magnetic tape. This restriction of the storage medium to sequential rather than random access involves, almost inevitably, the pre-sorting of text into a set of words in alphabetical order and the re-sorting of the information given by the dictionary into the original word order so that contextual information can be used.

Oettinger first describes information-processing machines in general and then gives a detailed account of the instruction code of Univac 1. A rather dull chapter on 'the structure of signs' follows, in which various self-evident features of coding —and particularly the coding of the Cyrillic alphabet—are discussed. This is succeeded by an account of automatic coding with particular reference to machine translation.

These preliminaries having been discussed, the problems of translation receive attention, and here the book becomes interesting. There is a detailed account of the work carried out at Harvard to construct an automatic Russian-English dictionary, and also examples of the results of its use. Much useful, and hitherto unavailable, linguistic-statistical information is presented, and the whole shows that a great deal has been achieved by the author and his group.

The book will be invaluable to all workers in the field, but since it presents a definitive description of one successful technique rather than a survey of many possible ones, it will be of less utility to the non-specialist.

A. D. BOOTH

Dictionary of Automatic Control *by* **Robert J. Bibbero.** *Reinhold, New York: Chapman & Hall, London. 1960. 282 pp. £2 5s.*

'The language of technology is, after all, a living language', says Mr Bibbero in his preface to this new American dictionary. Disclaiming any intention to produce 'merely another glossary or a compilation of ultra-precise definitions', he adds that he has set out to explain and discuss the important topics in the field of automatic control. He has probably succeeded better in his negative than in his positive objective, but that was to have been expected. The book is a small one, restricted to something over 500 'expanded definitions of automatic control terms', and it is therefore not comprehensive. Thus, under *V* we find 'valve action', 'valve capacity' and 'valve characteristic', and Mr Bibbero has—perhaps sensibly—left out 'valve' itself. There is much cross-reference to avoid repetition, and this sometimes causes a chain reaction that can be annoying. Those totally unfamiliar with the jargon may also be a little discomfited by a few of the more mysterious examples that they pass on the way (for instance, the formidable 'Tridop: see Dovap' on p. 25). There are some formidable sets of initials too, printed without full stops and therefore occasionally quite confusing (e.g. 'apt', which is defined in this dictionary in a way that would raise the eyebrows of a lexicographer). In his preface Mr Bibbero picks 'accumulator' as a specimen of the kind of word that acquires several different uses: but in the body of his book he gives only two, the computer and hydraulic-pneumatic senses, and then (leaning over backwards to avoid the 'ultra-precise') he describes the hydraulic or pneumatic accumulator as a means of storing *pressure*. Perhaps it would have been wiser to lean toward the ultra-precise than the ultra-loose in a work of reference. In fact, occasionally the explanations become so loose that they disintegrate into near-waffle.

A novel idea is the thesaurus-like index, which re-lists the entries under five main headings: theory, data processing, industrial control, aircraft etc. and telemetry, and components and design. If the exact word is not known, this index may help one to find it.

A.E.E.

Reliability

Electronic Equipment Reliability *by* **G. W. A. Dummer** *and* **N. Griffin.** *Sir Isaac Pitman & Sons Ltd. 1960. 274 pp. £2 5s.*

This book will be widely welcomed and could hardly have been published at a more appropriate time. From their eminence on component design the authors show that equipment reliability is much more than the correct use of the best components. The book provides a wealth of information on the analysis of faults, and the effect of environment on failure rates, then proceeds to discuss the reliability of standard circuits and details design procedures, ending with methods of predicting and calculating the reliability of systems. Although much of the information is derived from the military and missile fields it is clearly discussed on a cause-and-effect basis showing the effects of duty and environment on reliability. The book is, therefore, invaluable in the design of industrial control equipment although this is not its main intention.

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Extracts from the review in the November Issue of The Journal of the Society of Telecommunications Engineers.

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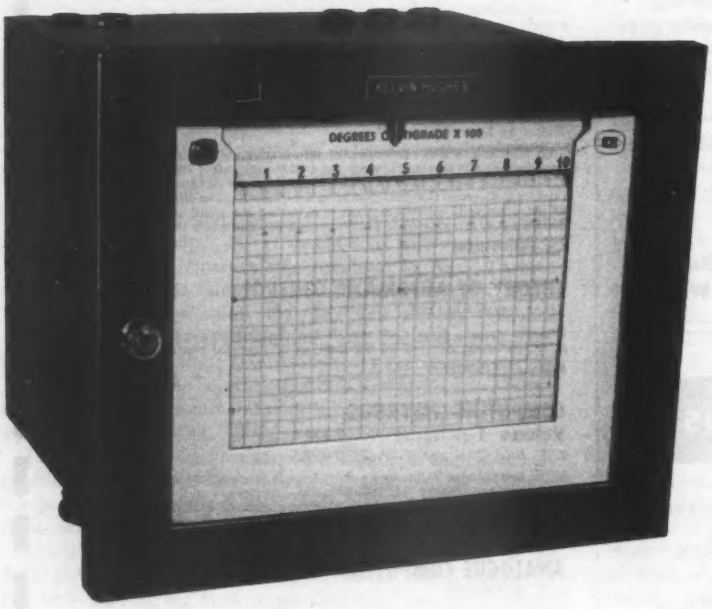

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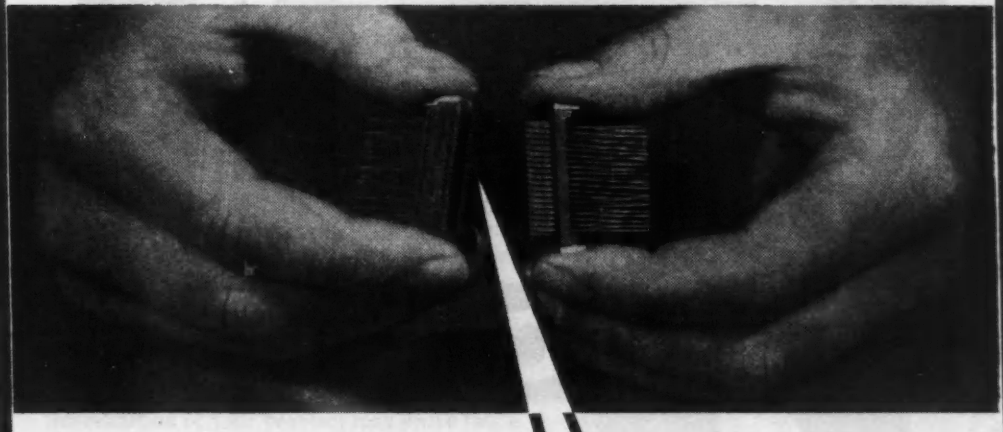

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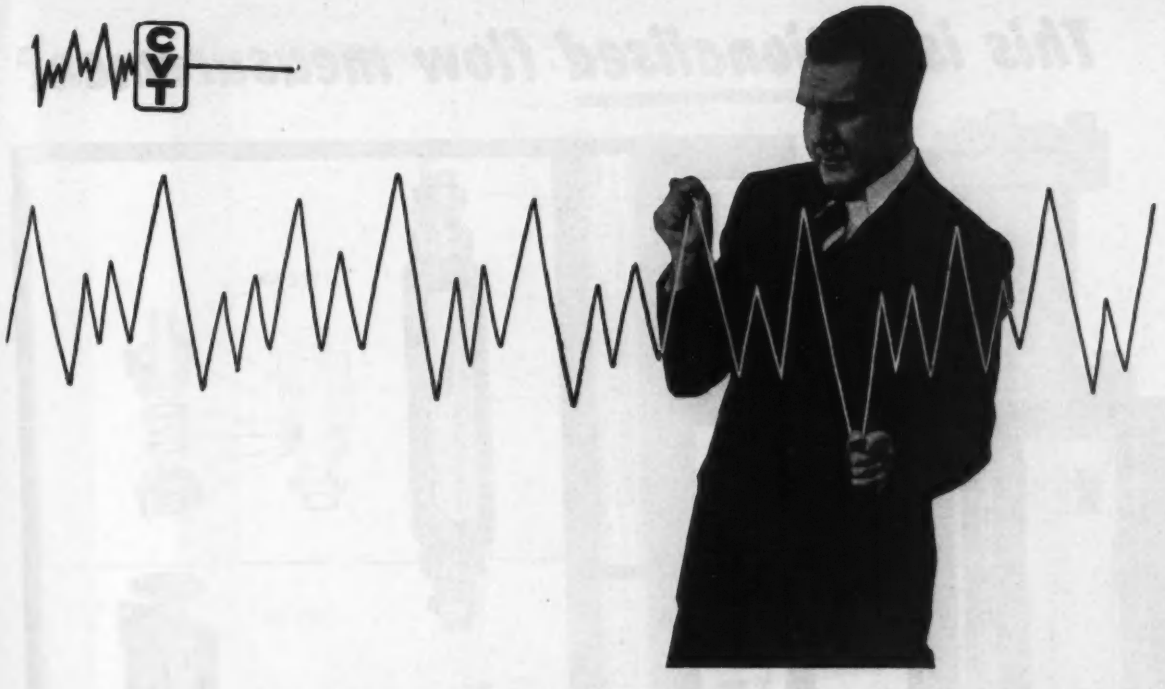

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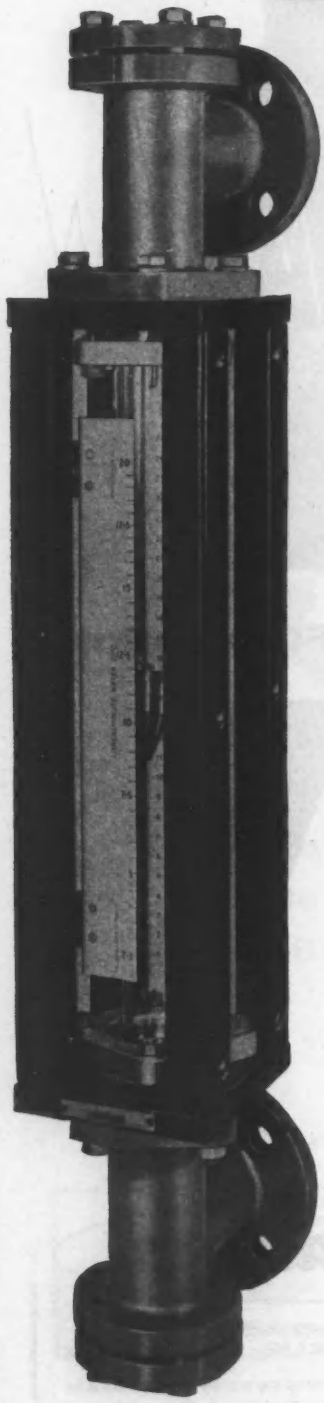

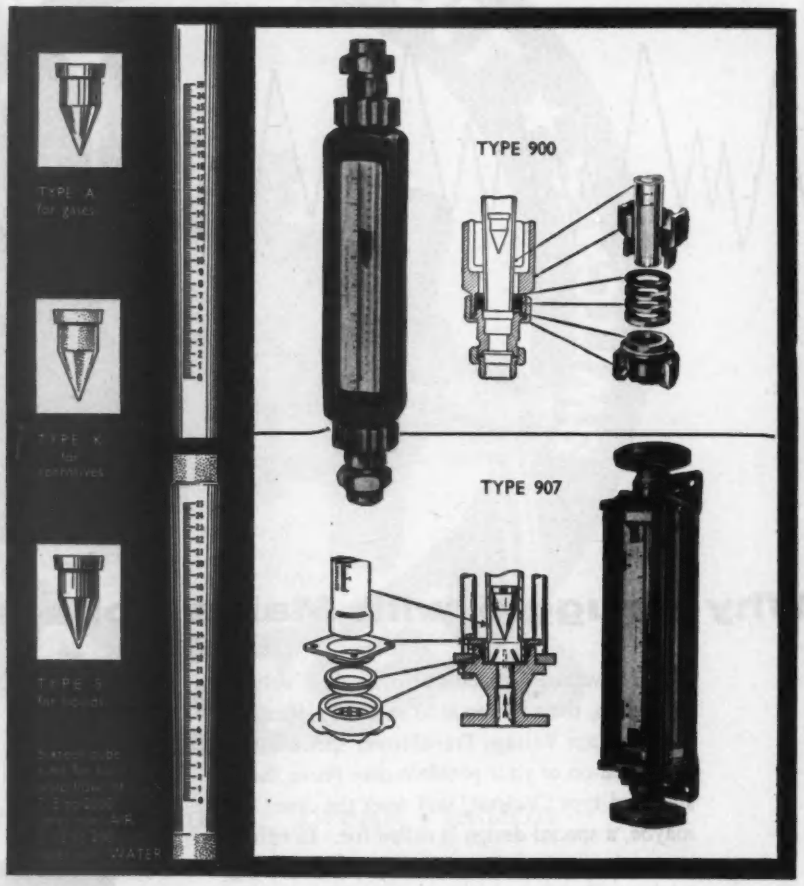

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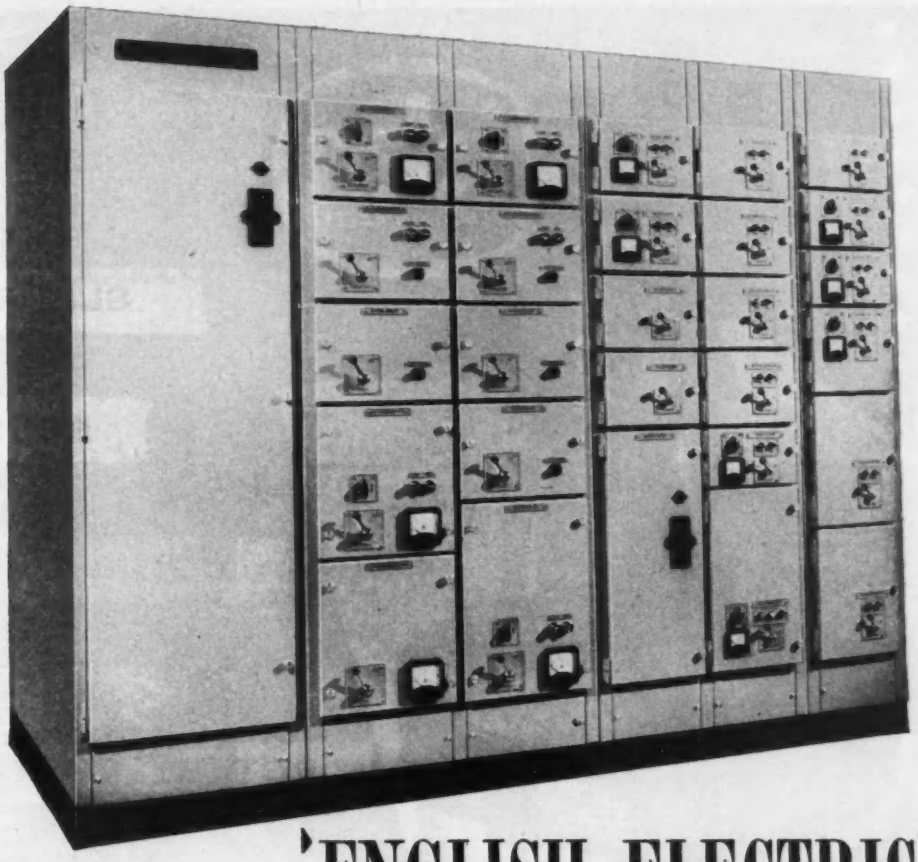

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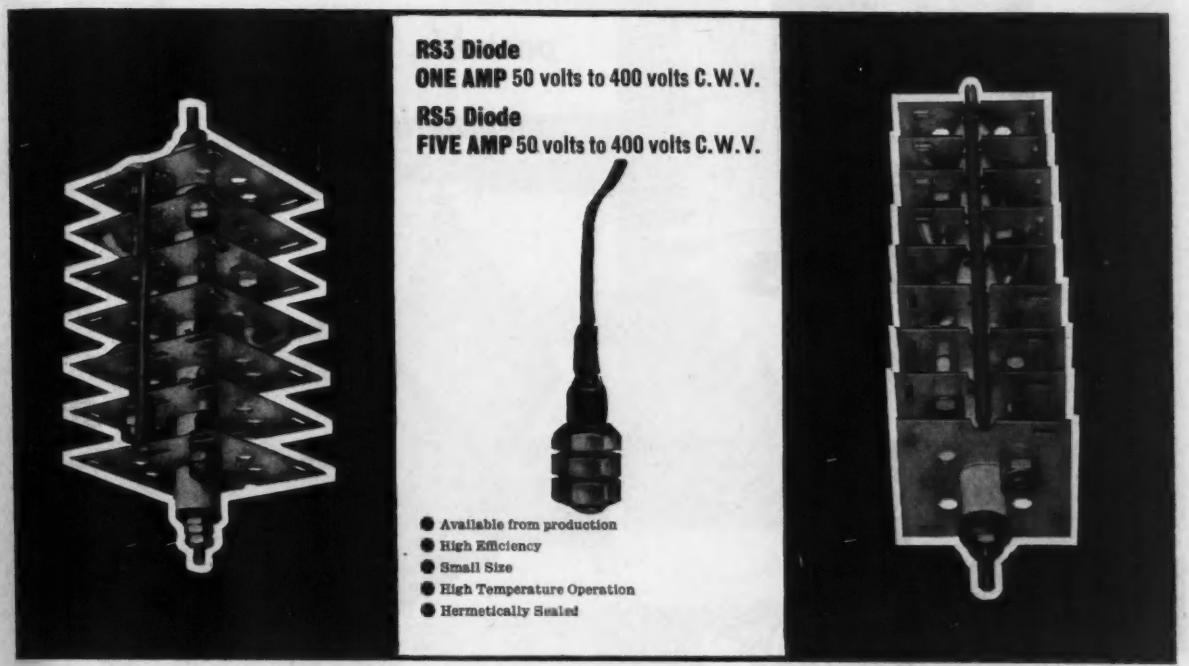

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SPECIFICATION

COIL and MOTOR:
—Wound for 110 V. or 230 V. 50 c.p.s. Consumption—8 V.A. approx. total.

SWITCH:
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RATING
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DELAY
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Projection—4½" (105 mm)
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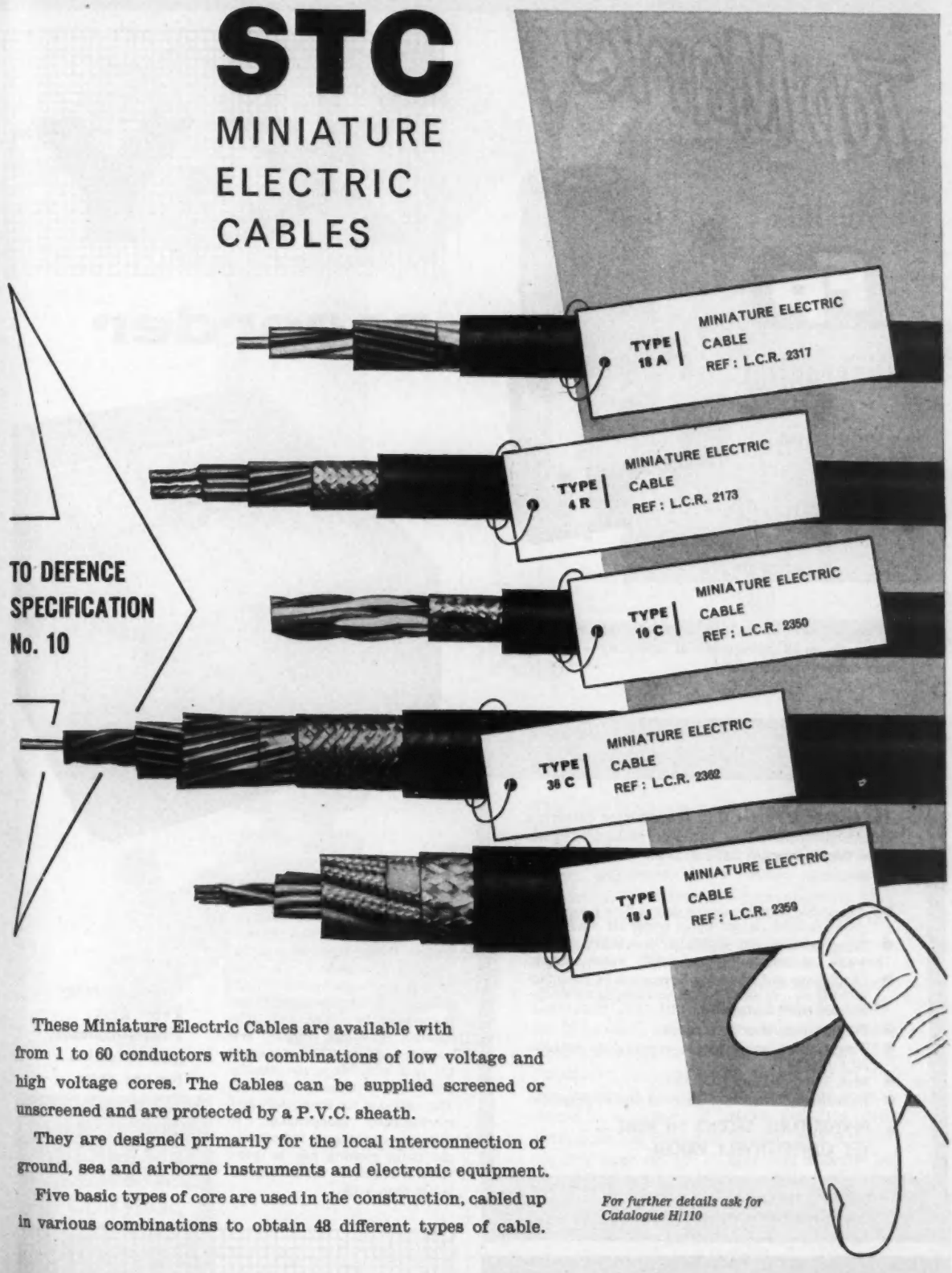
TYPE 18 A | MINIATURE ELECTRIC CABLE REF : L.C.R. 2317
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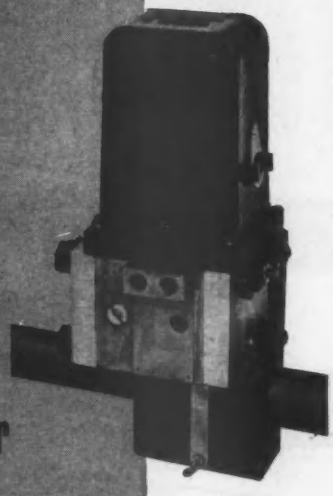
Differential Pressure Transmitter



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FPF15

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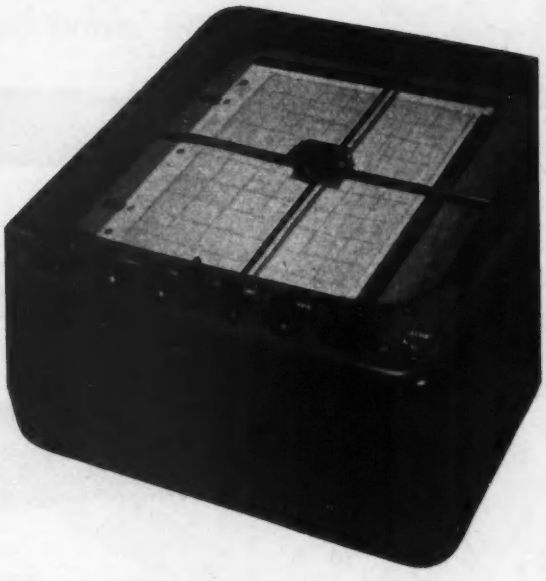

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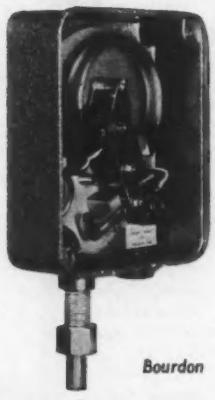
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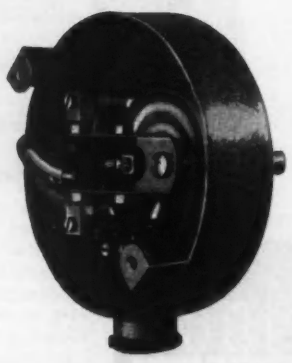
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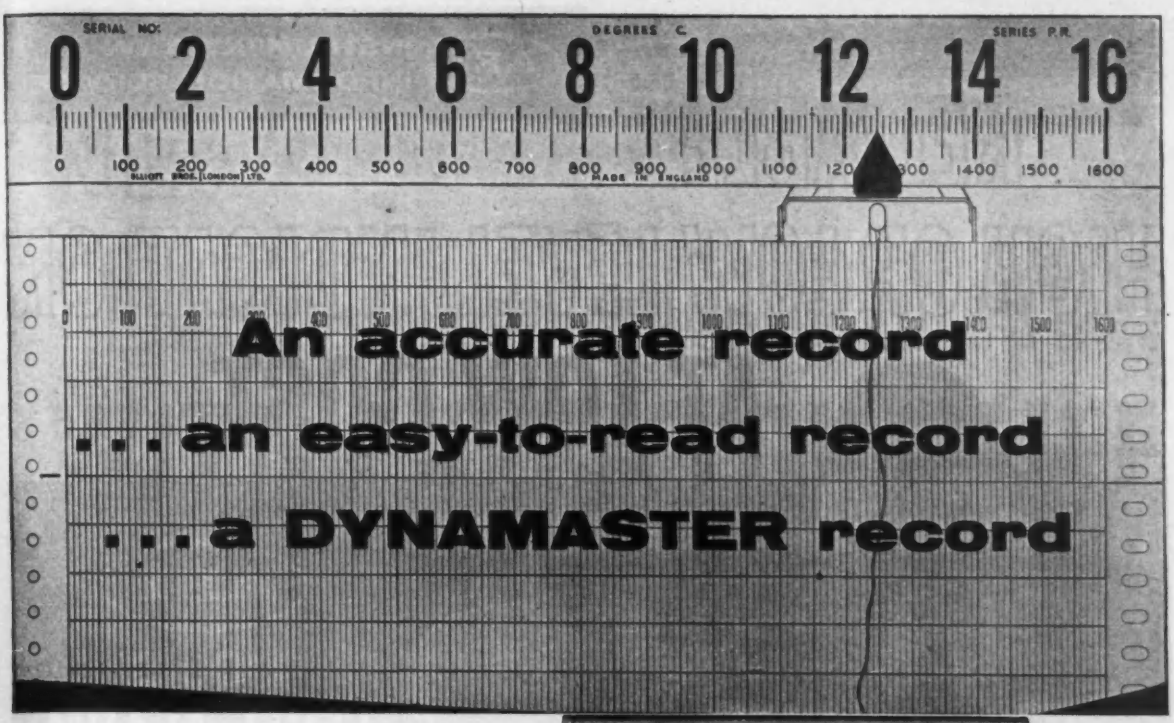
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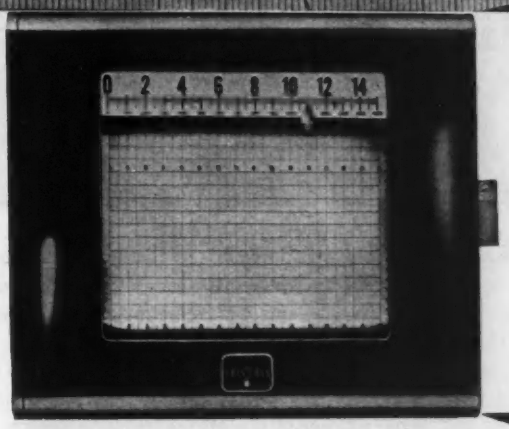

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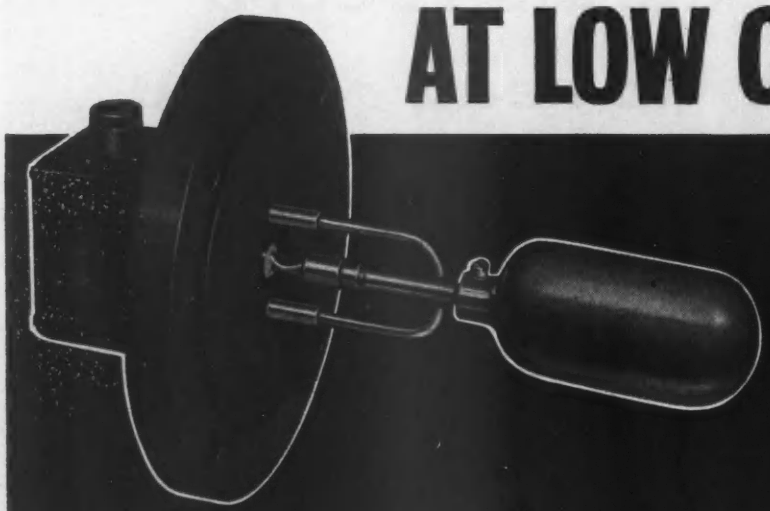

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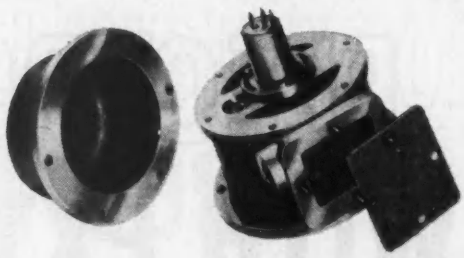

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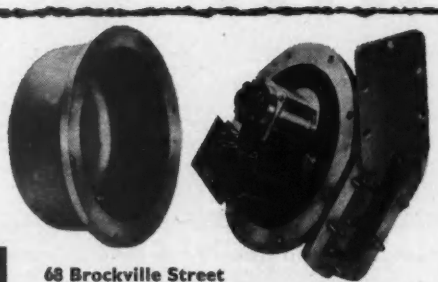

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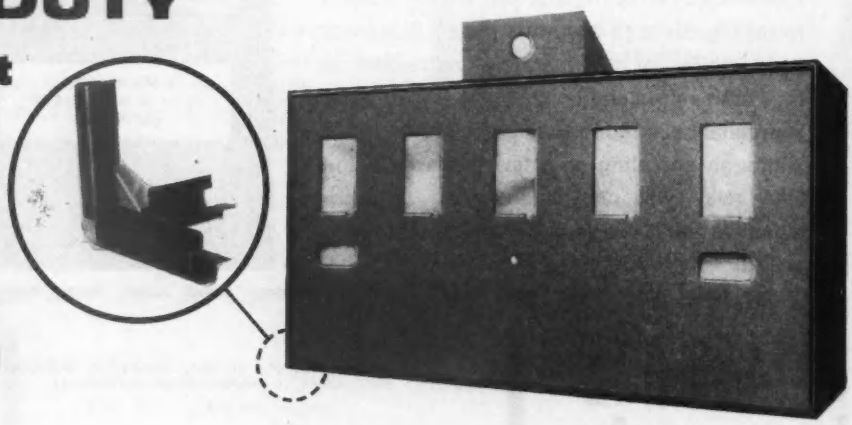

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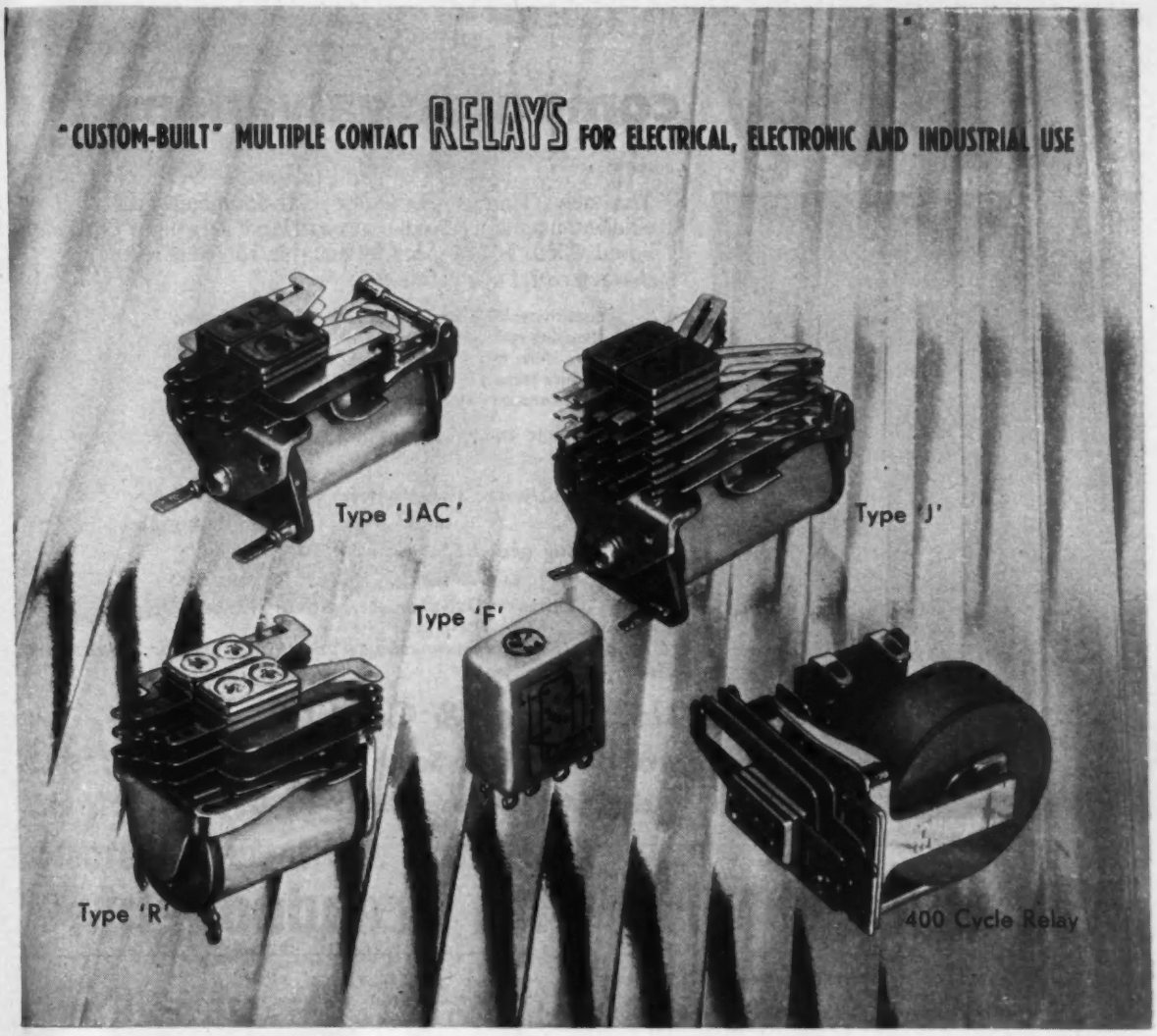

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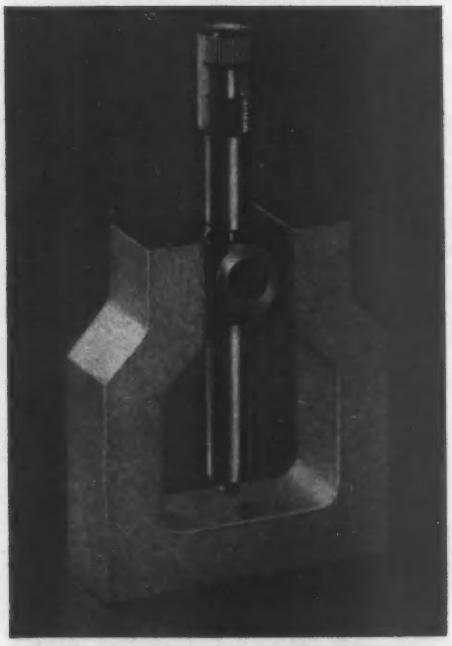

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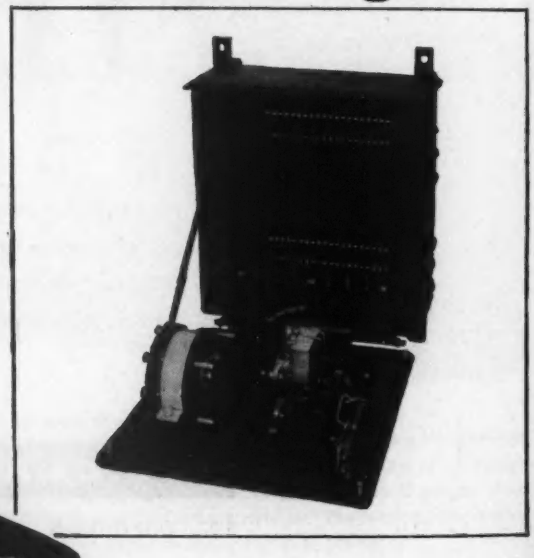

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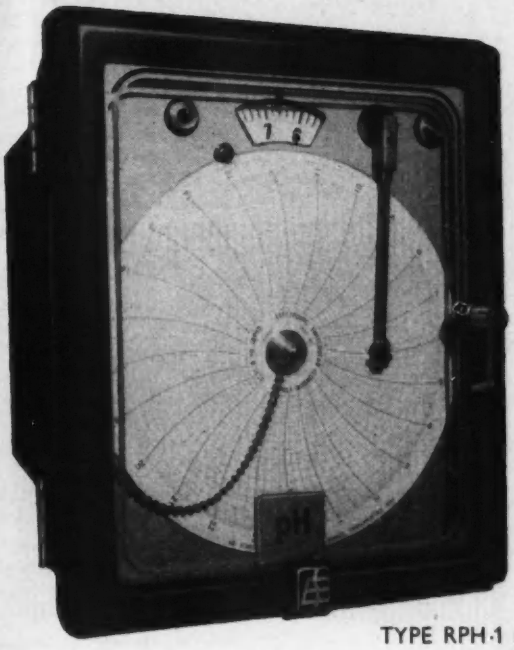

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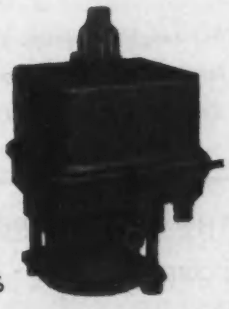

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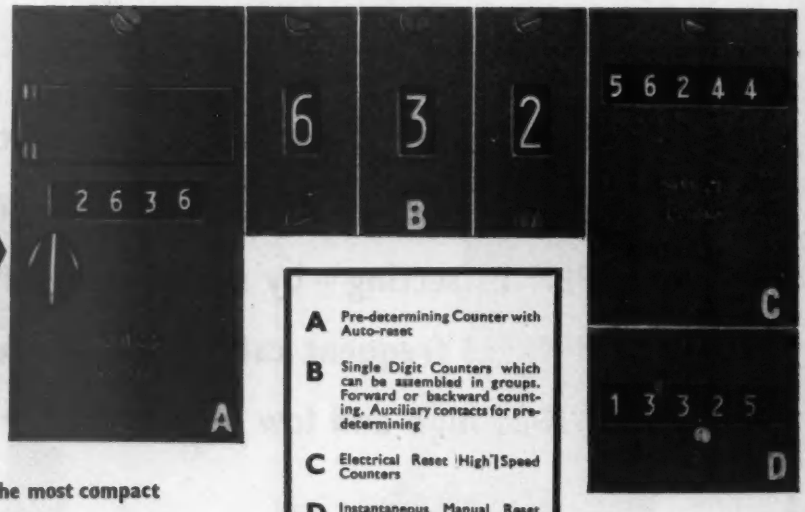

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(Because we like to see our customers satisfied!)

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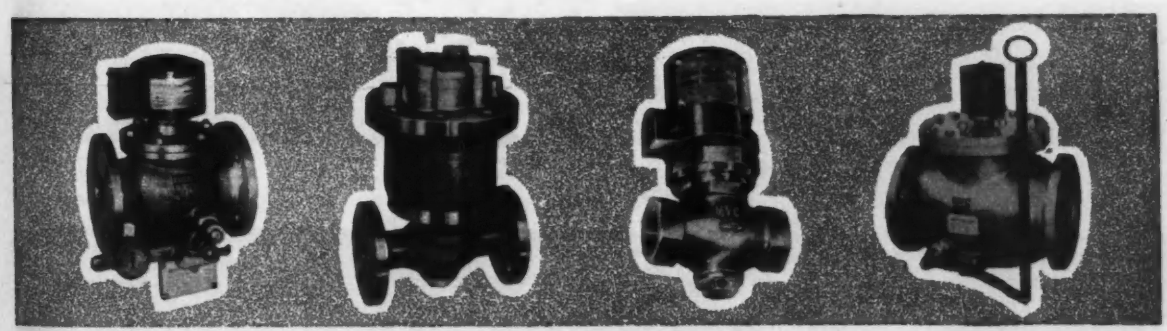
You'll find that expert consultation and advice cost you absolutely nothing at MVC. Our full experience is at your disposal. Many times, what has first appeared to be impossible has been achieved! Why not write *now* for our new comprehensive catalogue No. M.101 which contains full details of our complete range!



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The Magnetic Valve Company Ltd

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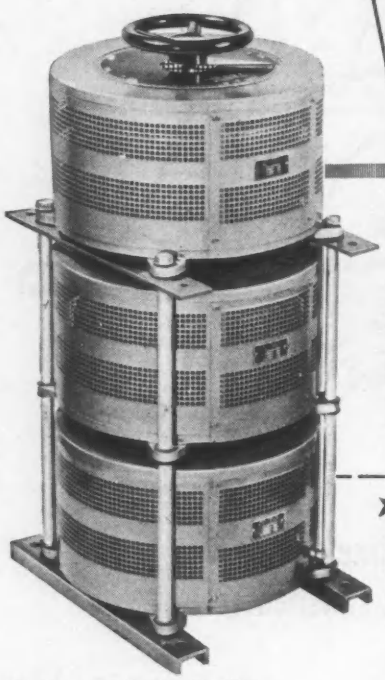
Variac WITH Duratrak ☆

Regd. Trademark



This 3-gang assembly, Type 50-BMG3, will control 22·5kVA, 3-phase or single-phase according to connection. Larger assemblies can be made.

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This small Variac, Type V-5HMTF, provides an output of 0-270 V, 2 A, from 240 V 50 c/s mains. A still smaller model, Type V-3H is rated at 1 A.

☆ Duratrak? Duratrak (Regd. Trademark) —a patented* feature exclusive to Variac—is a special plated contact surface giving longer life, increased overload and surge capacity and maximum economy in maintenance. Duratrak is now standard on all models except Series 50.

*U.K. Pat. No. 693406

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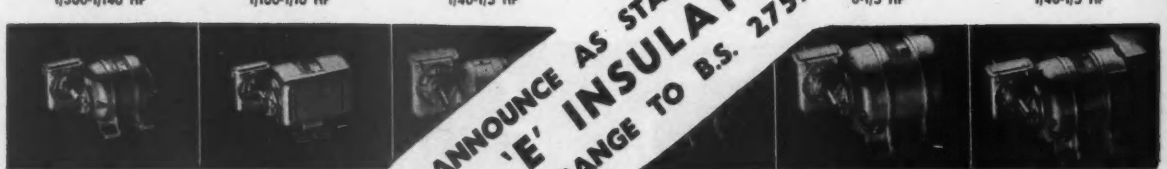

Shaded Pole Constant Speed 19-330 RPM | Series Wound Variable Speed 25-800 R | Capacitor Constant Speed 17-680 RPM | Capacitor Constant Speed 20-700 RPM | Split Phase Constant Speed 20-700 RPM

WE ANNOUNCE AS STANDARD CLASS 'E' INSULATION THROUGHOUT OUR RANGE TO B.S. 2757 : 1956

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PNEUMATIC

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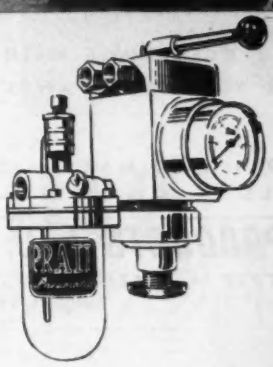
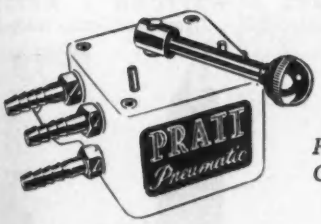
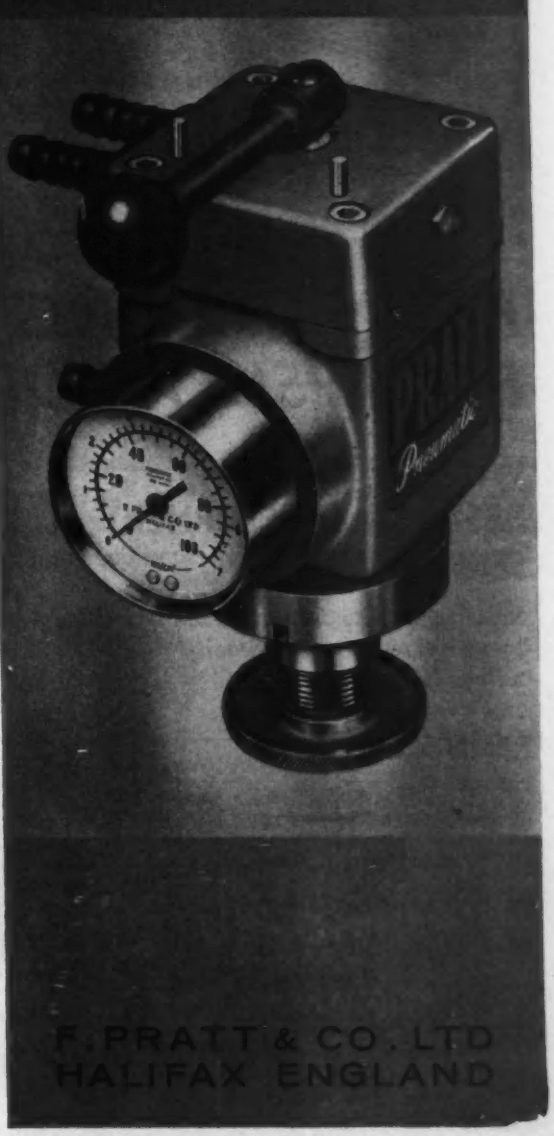
Pratt Hand Operated Air Control Units Type V.6 Fitted with Oil Mist Lubricator





Pratt Hand Operated Control Valve Type V.2



This unit combines a hand operated control valve, dial pressure gauge and pressure reducing valve in one neat, compact and efficient assembly. The design of the valving mechanism is such that extremely long life and finger light operation is guaranteed. The valve disc is fully-floating and consequently any tilt of the operating shaft due to wear over a long period of time does not affect the efficient working of the valve. Essential working parts are non-ferrous to ensure freedom from corrosion due to moisture in the air line. Tapped holes are provided in the rear of the body for fixing. Removal of the pressure gauge will expose bolt holes for front fixing if required. Standard port size ¼" B.S.P.

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Famous for Workholding for 100 Years

Pratt Control Units cover a wide range of applications in the Pneumatic field. We shall be pleased to send you full details on request.

F. PRATT & CO. LTD
HALIFAX ENGLAND

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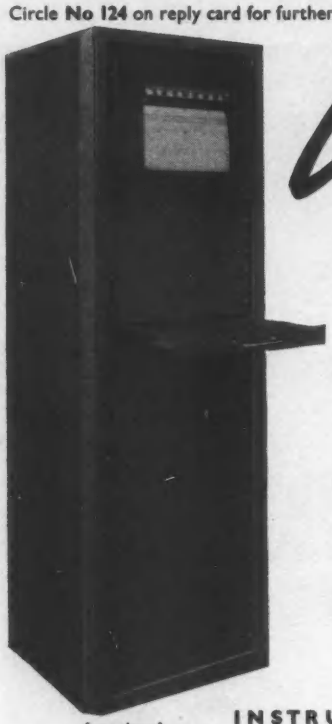

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EMPTY?

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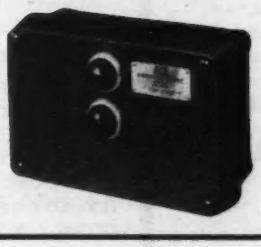
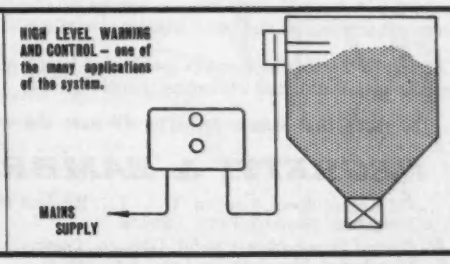
Both units are of extremely robust construction and completely weather-proof. No adjustments are necessary on installation, maintenance is negligible, and the system is backed by nationwide service facilities. Full technical information is yours for the asking, or we will arrange for one of our engineers to call and talk over details with you.





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Firth Cleveland Instruments Ltd., 7 Cleveland Row, London, S.W.1 Tel: WHitehall 3100 A MEMBER OF THE FIRTH CLEVELAND GROUP

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AETEC 8"

Thermo-electric Indicators, and Resistance Thermometers

Thermocouple Pyrometer

Stability is a pre-requisite of accuracy—maintained over many years of use. The Galvanometer fitted in the new range of Negretti & Zambra Aetec Thermo-Electric Indicators, Controllers and Electrical Resistance Indicators is of completely new design embodying modern techniques and materials giving high torque/weight ratio, ample gap between moving coil and magnet assembly, high sensitivity and low period.

IMPORTANT FEATURES ARE:

Accuracy guaranteed within ± ·5% of full scale deflection.
Printed circuits in Multipoint Indicators and Switchboxes to give high reliability and low cost.

Ease of adjustment and maintenance—chassis quickly removable from anti-magnetic screening case.

8-inch scale,

Multi-point indication—up to 5 points (thermocouple type) with built-in switch.
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Ranges—up to 1600°C (thermocouple type) and up to 500°C (resistance type).

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All Negretti & Zambra instruments are covered by a 2-year guarantee against defect of workmanship and materials.

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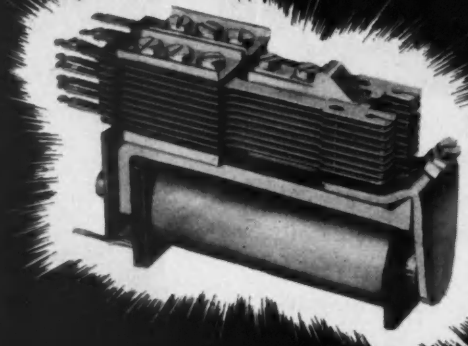
Still THE MOST RELIABLE
K 3,000 type RELAY



"PLUG-IN"

3000 type RELAY

WITH TRANSPARENT DUST COVER AND PLUG-IN BASE
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Now supplied as follows:-

● 6 CHANGE-OVERS LIGHT DUTY ● 6 MAKES OR 6 BREAKS HEAVY DUTY ● 2 CHANGE-OVERS HEAVY DUTY AND 2 CHANGE-OVERS LIGHT DUTY ● TRANSISTORISED TO OPERATE AS LOW AS 3 MICRO-AMPS ● A.C. OPERATION FOR: 6V., 12V., 50V., 110V. & 250V. A.C. ● DOUBLE WOUND COILS ● P.T.F.E. INSULATION ● OPERATE & DELAY UP TO 5 SECONDS

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C.202 500 A.M.P rated T.P. Contactor, fitted one normally open and one normally closed auxiliary contacts, as supplied for use as remote controlled isolators for part of the equipment supplied from each masterboard of the S.S. Canberra.

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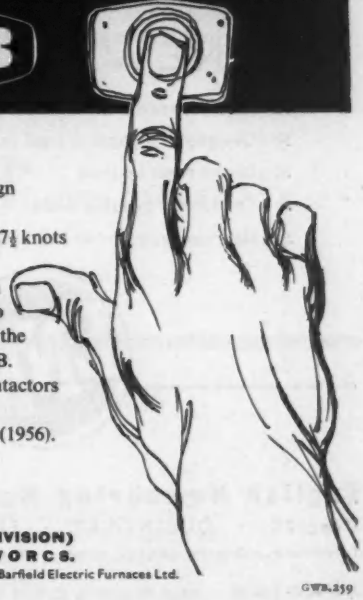

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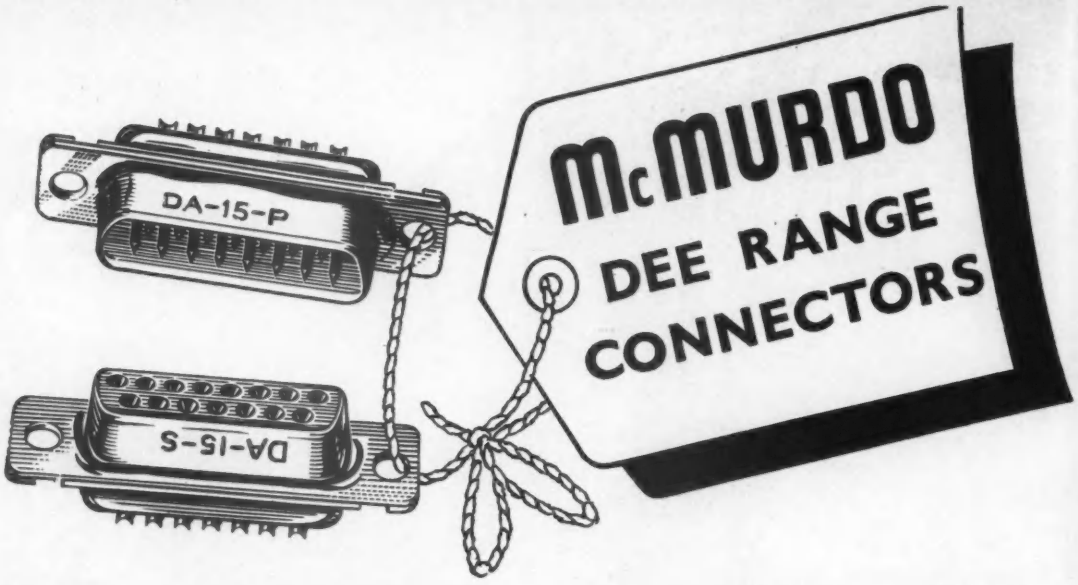

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Flexible and rigid Tecalemit nylon tubing now outperforms metal, other plastics and rubber for industrial and automotive oil and fuel lines. Tecalemit Tubing is fitted as standard by such great names as Aston-Martin, Austin, Ford, International Harvester, Jaguar, Massey-Ferguson, Rover and many large industrial users including, of course, Tecalemit industrial lubrication installations.

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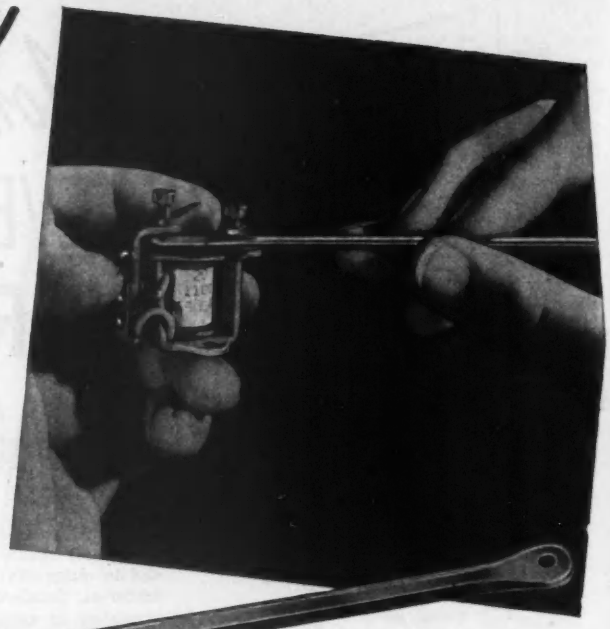
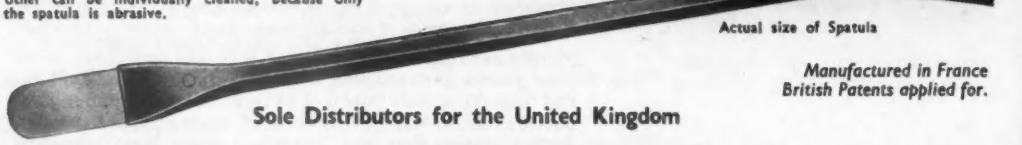


Actual size of Spatula



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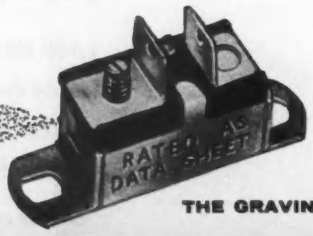

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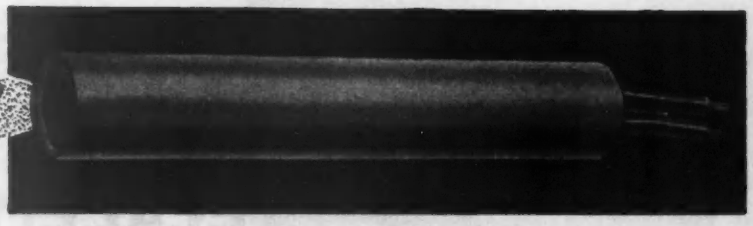

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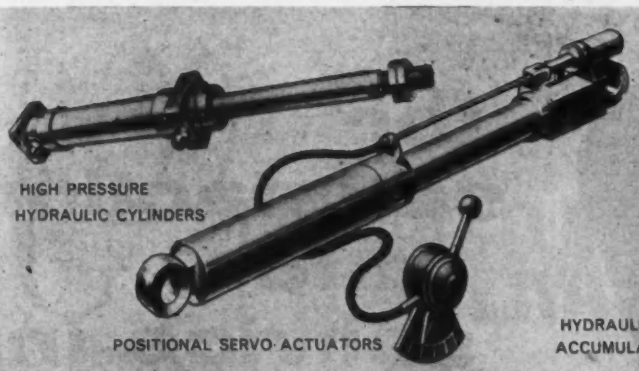
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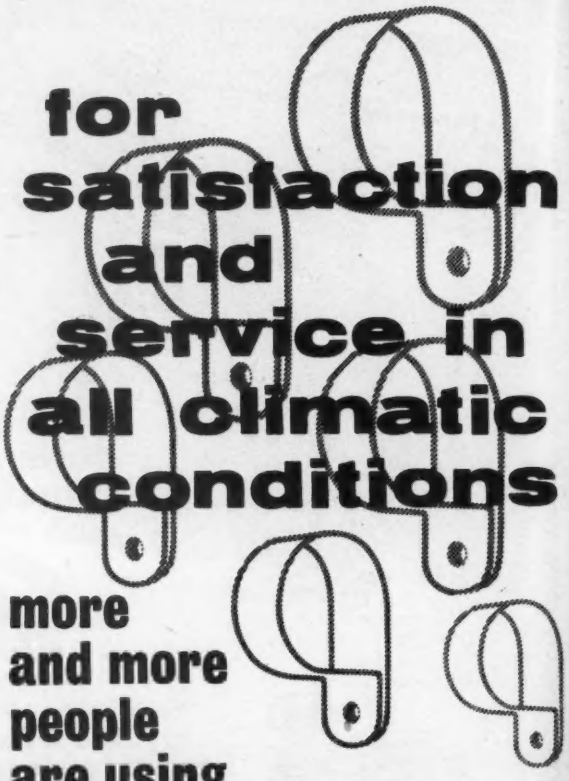

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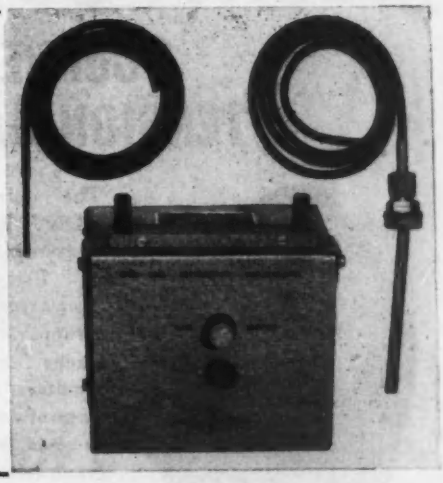

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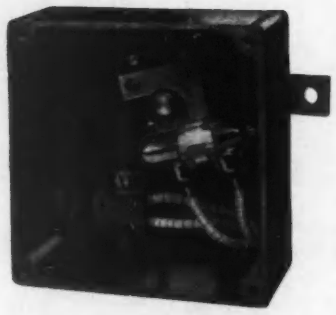

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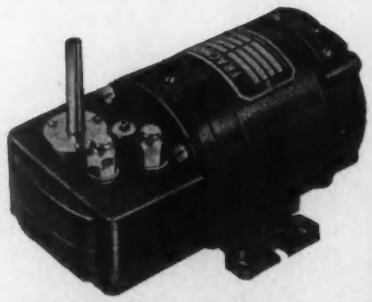

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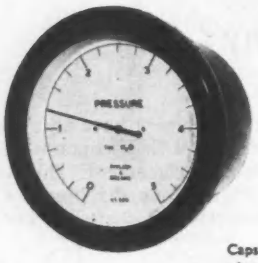

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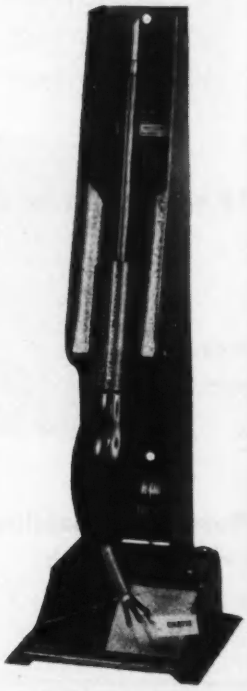

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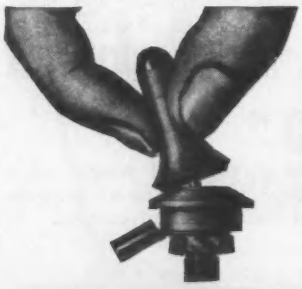

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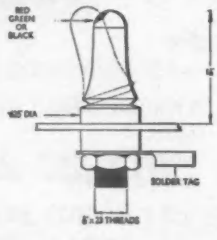

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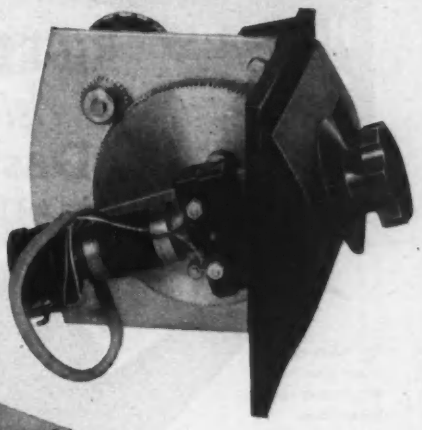

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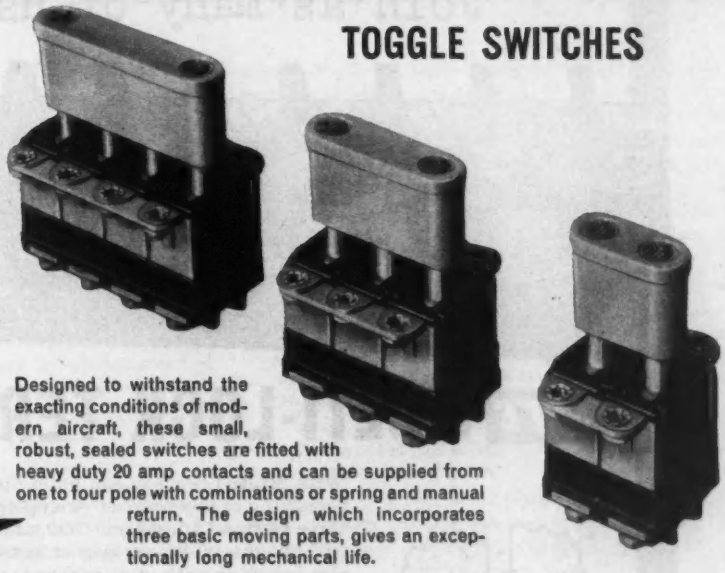

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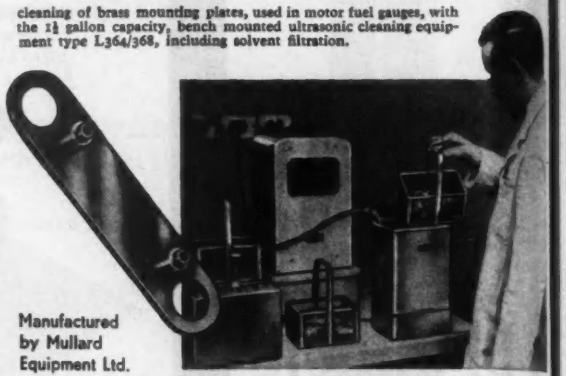

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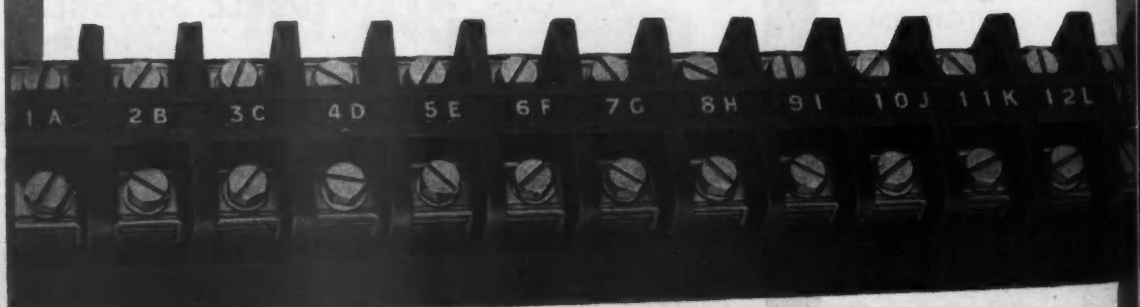

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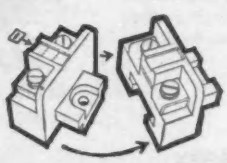

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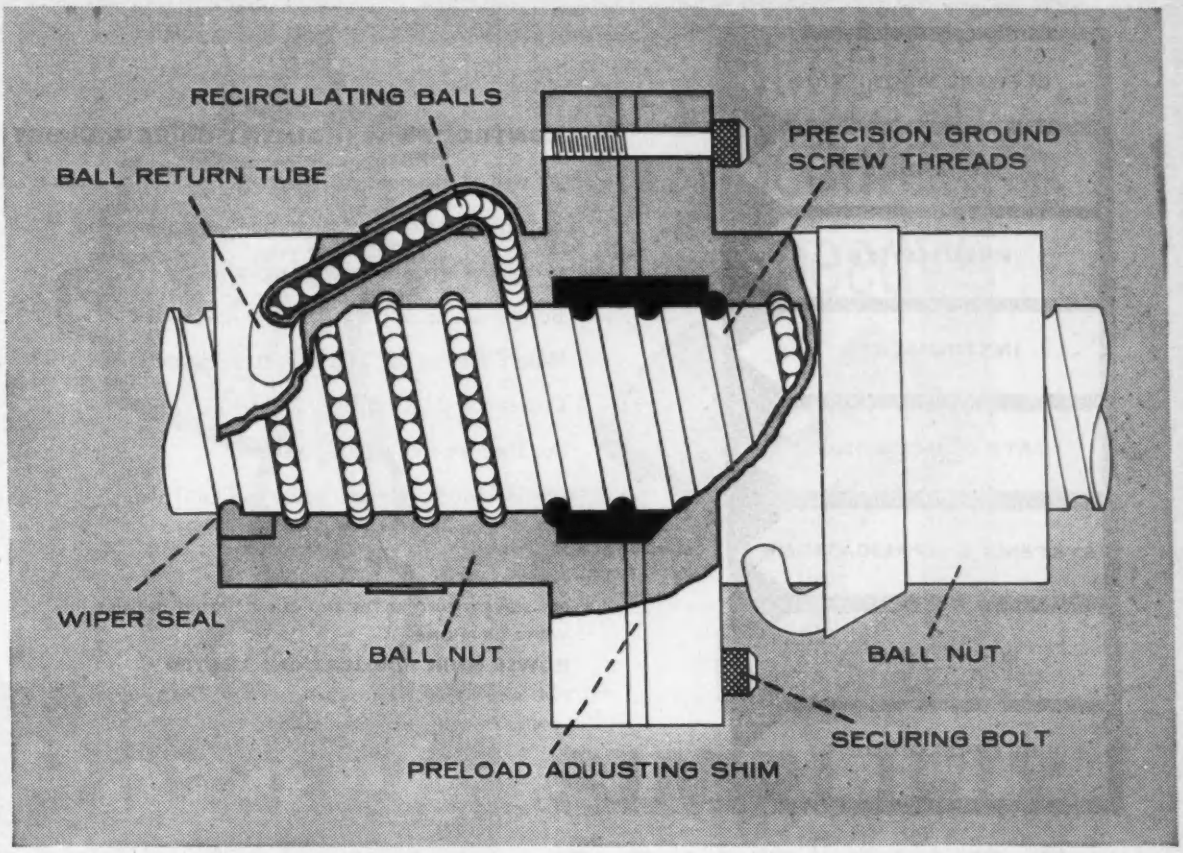

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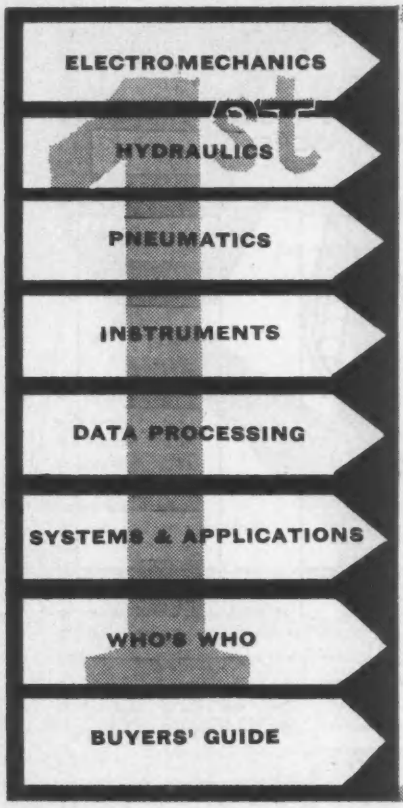

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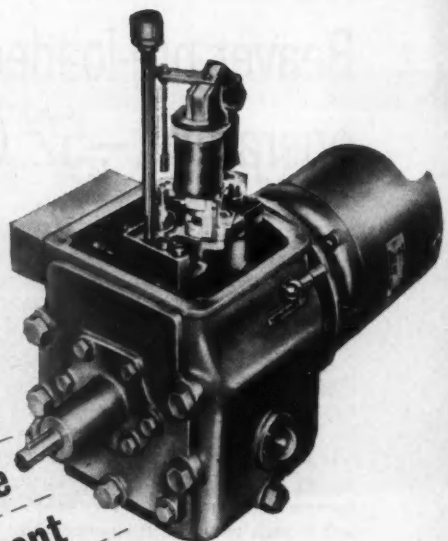

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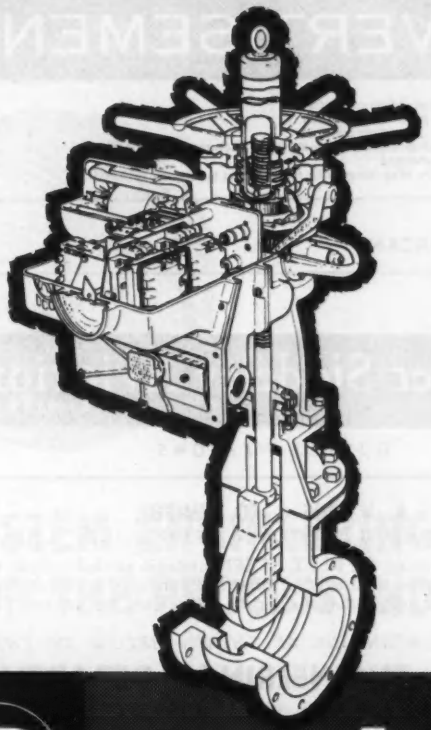

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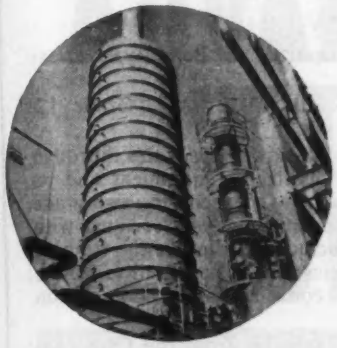

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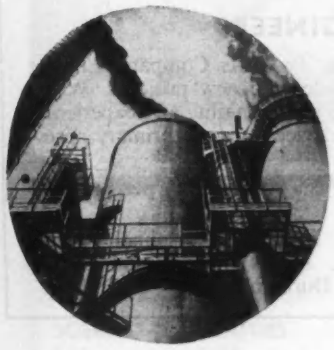

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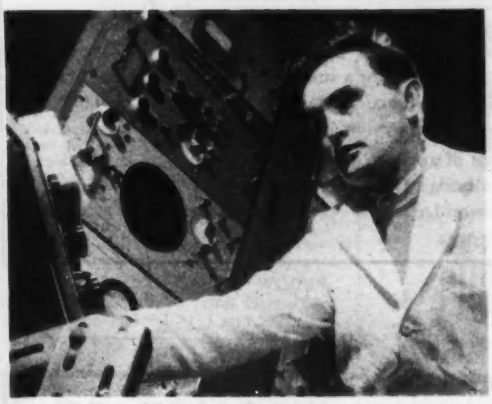

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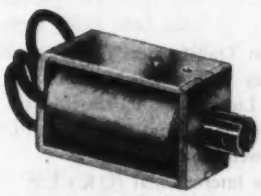

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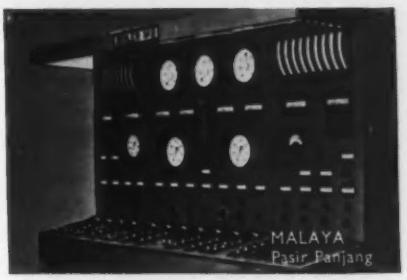
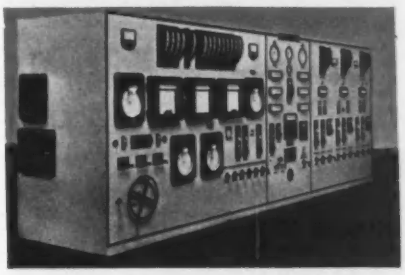
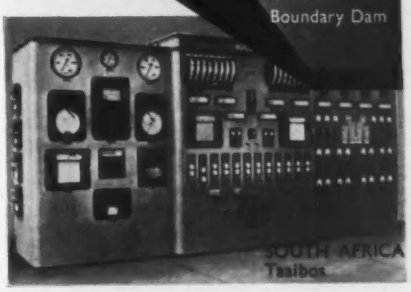
Yet the Company, conscious that its growth to world-wide proportions was largely built up on a tradition of service to users big and small, is always most ready to meet the more simple requirements of the industrial boilerhouse—such as the draught gauge, the rotary-shunt pipeline meter for totalizing steam or water flow, and the *Multelec* CO_2 (or O_2) and temperature recorder.

From the single measuring unit to the engineering, supply, installation and commissioning of a complex automatic-control scheme complete with panels, experience matters.







KENT **masters of instrumentation**

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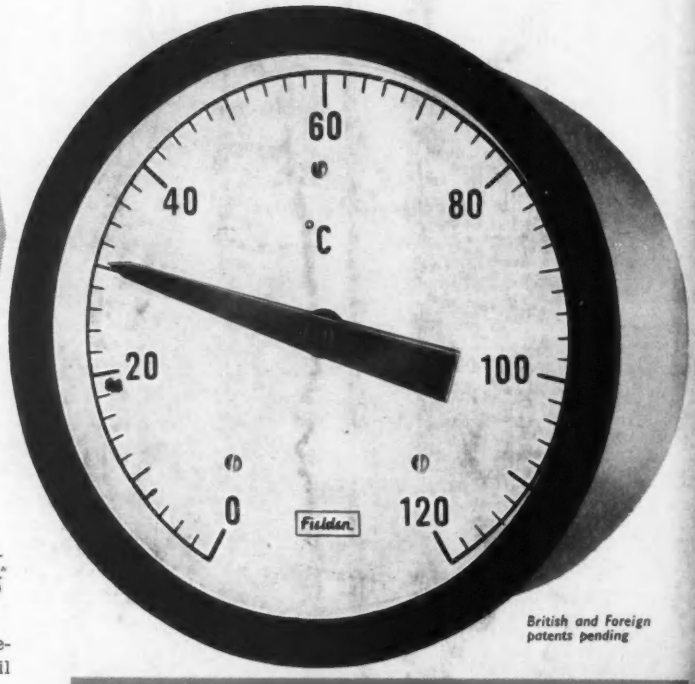
CONTROL

NEW



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VERY ROBUST. Sealed 6" diameter instrument, with measuring bulb in ¼" diameter stainless steel sheath.

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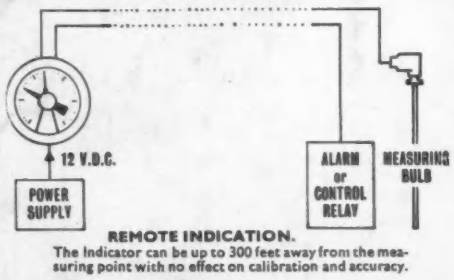
EASILY FITTED. Simple clamp mounting with robust terminals. No fragile capillary tubes or expensive compensating cable — simple wiring only required.

ACCURATE AND RAPID RESPONSE. Reproductibility better than 0·25% on 13" scale, response time 1 second.

75 TEMPERATURE RANGES in °F and °C for temperatures up to 850°C.

'BIKINI' REG'D TRADE MARK TEMPERATURE INDICATOR



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The Indicator can be up to 300 feet away from the measuring point with no effect on calibration and accuracy.

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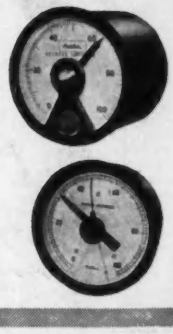
The Indicator can be supplied with an adjustable control contact for use with local or remote alarm or control relay.



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